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A description of work accomplished under contract between the California Institute of Technology and the National Aeronautics and Space Administration for the period January 1 through December 31, 1993.

Jet Propulsion Laboratory
California Institute
of Technology
Pasadena, California

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Cover: The core region of the spiral galaxy M100, tens of millions of light years away, was captured by the Hubble Space Telescope's Wide Field/Planetary Camera 2 in December 1993. The camera completely restores the Earth-orbiting telescope's imaging capability.

The Jet Propulsion Laboratory (JPL) is an operating division of the California Institute of Technology (Caltech) that performs research, development and related activities for the National Aeronautics and Space Administration (NASA). A Federally funded research and development center, JPL is the nation's lead center for the automated exploration of space and is responsible for a broad range of major robotic planetary missions and space science instruments. The Laboratory also conducts basic and applied scientific and engineering research and creates instruments and techniques to study Earth and its environment.

In addition to its work for NASA, JPL carries out research for the Department of Defense and other Federal agencies as well. Many developments are also being shared with the private sector. JPL became part of NASA on January 1, 1959; today the Laboratory is an internationally known institution with an annual budget of over \$1 billion. Located in the foothills of the San Gabriel Mountains above Pasadena, California, JPL occupies 152 buildings on 177 acres and employs more than 6,000 people.

2

DIRECTOR'S MESSAGE

4

FLIGHT PROJECTS

12

EARTH AND SPACE SCIENCE

20

TELECOMMUNICATIONS SYSTEMS

28

ADVANCED TECHNOLOGY

36

APPLICATIONS PROJECTS

44

INSTITUTIONAL ACTIVITIES

An annual report is often retrospective, emphasizing program completions and accomplishments on projects and tasks in progress. Thanks to our talented and dedicated staff, JPL had many significant achievements in 1993. Our attention, however, should also focus toward the year (and years) ahead, for it is clear that the remainder of this century will be a time of transition — for the United States, for NASA and for the Laboratory.

Looking back on 1993, JPL can be proud of many events: aerobraking the Magellan spacecraft into a lower, nearly circular orbit to obtain a map of Venus' gravity field; accurately guiding the Galileo spacecraft to an encounter with the asteroid Ida; deriving exceptionally precise data on Earth's oceans from the TOPEX/POSEIDON satellite; through the successful efforts of the space shuttle Endeavour team, replacing the Hubble Space Telescope's Wide Field/Planetary Camera with a new camera that returns images having the unmatched clarity expected from the original instrument; deploying the All Source Analysis System that led to a major reorganization of military intelligence operations, and adding 16 new companies to our expanding Technology Affiliates Program.

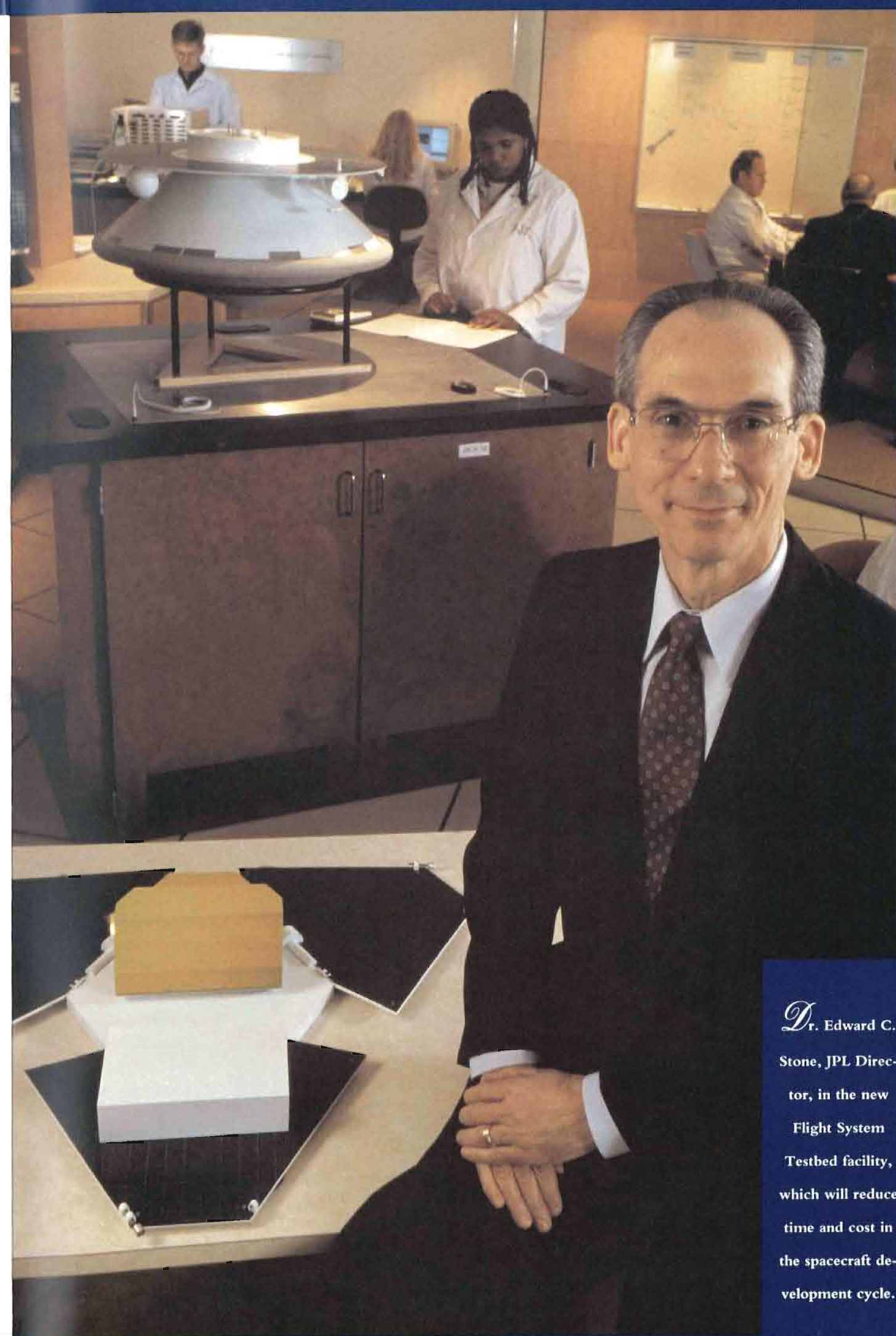
In this otherwise outstanding year, we suffered the loss of the Mars Observer spacecraft just as it approached orbit insertion at Mars. We are determined to rebound from this setback by incorporating the lessons learned into the development of future spacecraft and by formulating a new Mars program.

In 1994, we will twice fly the Space Radar Laboratory as well as refly the Atmospheric Trace Molecule Spectroscopy (ATMOS) instrument aboard the space shuttle. JPL will also continue the development of the Cassini and Mars Pathfinder missions and of several major Earth-observation instruments. Next summer, with our European Space Agency partners, we will observe the Ulysses spacecraft's passage through the Sun's south polar region. We will also deliver surface-oxidation detectors for integration into two Mars landers to be launched by Russia in 1994.

In the background of all these activities are pervasive political, economic and social changes. In this environment, the Laboratory will be challenged to ensure that our programs are relevant to the nation's priorities of undertaking only endeavors of high scientific or technical merit. Furthermore, we must share our technology development successes with industry through an enhanced technology development and commercialization program.

To meet these challenges, JPL is determined to extend and strengthen ties with partners in academia, industry and other agencies. And, most important, we are determined to continue improving ourselves, our processes and our products through the tools and attitudes of Total Quality Management.

E. C. Stone



Dr. Edward C. Stone, JPL Director, in the new Flight System Testbed facility, which will reduce time and cost in the spacecraft development cycle.

1993 saw discovery and development

Galileo, on its way to a December 1995 rendezvous with Jupiter, flew by the asteroid Ida. Cassini, progressing toward launch in October 1997, selected contractors for the spacecraft's detail design and fabrication. Magellan moved into a new orbit around Venus to enable the gathering of high-resolution gravity data.

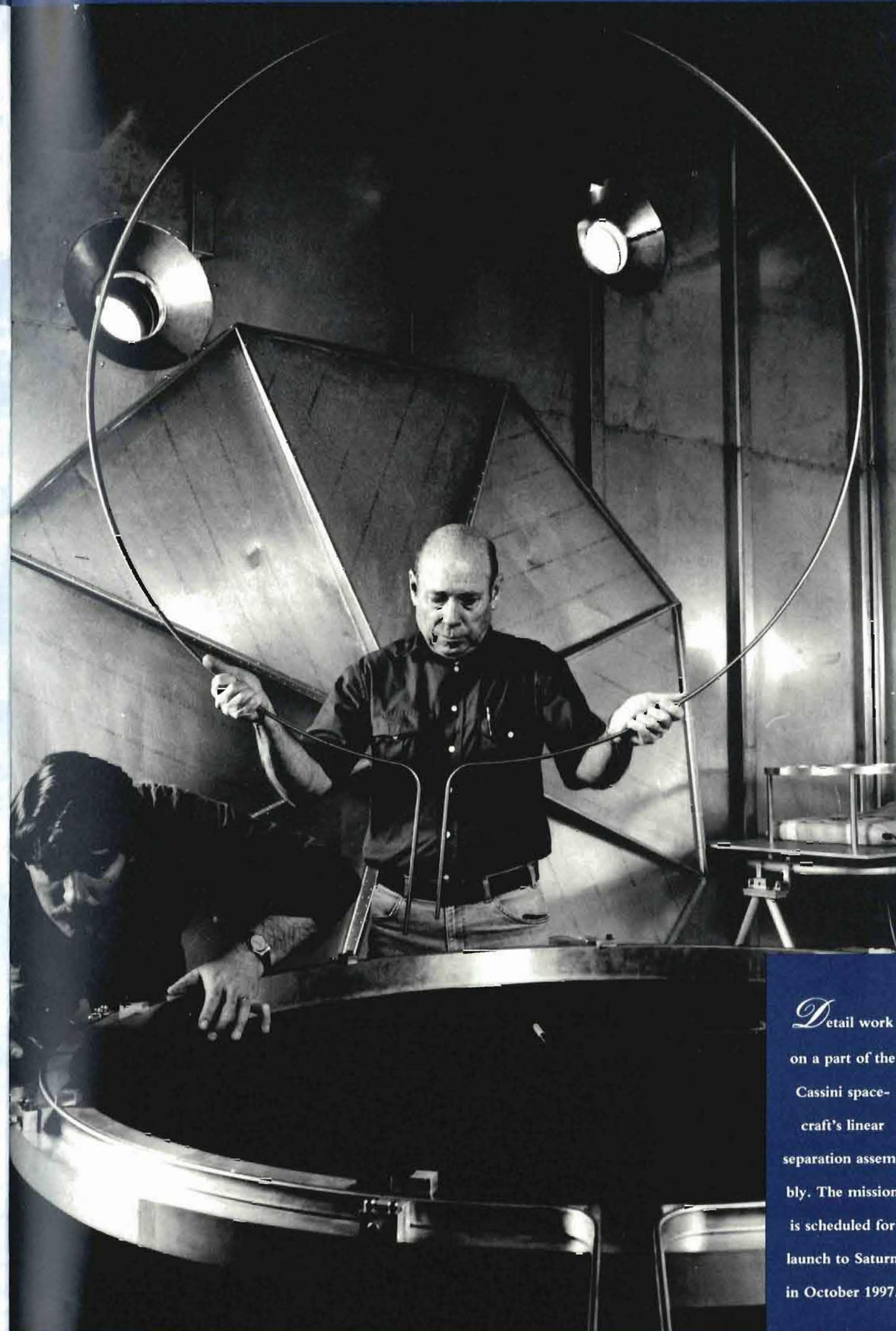
TOPEX/POSEIDON, completing its first year of Earth observation, uncovered events in the Pacific Ocean that were linked to weather conditions on the East and West Coasts. Ulysses has made many discoveries en route to a passage through the Sun's south polar region next summer.

The year also included a setback: Mars Observer, just days before

entering orbit around Mars, failed to resume contact with Earth; recovery efforts proved fruitless.

But the future bodes well. A mission to Pluto is in development. As part of the transition to space ventures that are small, inexpensive and highly focused, JPL is considering a series of missions incorporating advanced concepts. In addition, the Flight System Testbed was developed to help create the smaller spacecraft required for future exploration.

Even Mars is still within reach: the Mars Environmental Survey Pathfinder mission completed the first phase of subsystem deliveries in preparation for a December 1996 launch.



Detail work on a part of the Cassini spacecraft's linear separation assembly. The mission is scheduled for launch to Saturn in October 1997.

GALILEO

In August, the Galileo spacecraft flew by the asteroid Ida, an irregularly shaped main-belt asteroid believed to be a remnant from the breakup of an earlier body. Ida is about twice as large as Gaspra, the first asteroid closely observed, also by Galileo, in 1991. The highest resolution image of Ida, returned this fall, shows that the asteroid is extensively cratered, with many craters larger than those seen on Gaspra. The remainder of the Ida data will be returned to Earth next spring. The Ida encounter required close teamwork by flight teams at JPL and the Deep Space Network stations around the world.

For three weeks this spring, Galileo, with the Mars Observer and Ulysses spacecraft, performed the most sensitive search to date for very low frequency gravitational waves. The projects are currently involved in the arduous task of sifting through the data to determine if a gravitational wave was detected.

In October, Galileo performed its largest propulsive maneuver to date, to target the atmospheric probe for its entry into Jupiter's atmosphere in December 1995. The flight team and the Deep Space Network also conducted several important tests of Galileo's communications system this year to significantly increase the spacecraft's transmission rate during the orbital mission at Jupiter.

CASSINI

The Cassini mission to explore the ringed planet Saturn is moving forward toward launch in October 1997. In 1993, the contractors were selected for the detail design and fabrication of the elements of the spacecraft system. The spacecraft structure is being developed rapidly to minimize work force and accommodate an early freeze of interfaces, which is essential to the spacecraft development plan. The flight-model engineering flight computers

have been fabricated and are being tested in four subsystems. The Huygens probe — which will investigate Titan, Saturn's largest moon — is being built by the European Space Agency. Preliminary hardware and interface design reviews have been completed for all 12 of the science instruments for the Cassini orbiter. The science instruments are scheduled to be delivered to JPL in 1996.

Cassini is a truly international venture. In addition to some 1,300 academic and industrial partners in 16 European countries, more than 3,000 people are participating across 32 states in the United States. The mission is managed by JPL, while a team based at the European Space Agency's European Space Research and Technology Centre in the Netherlands is managing development of the Huygens probe. Agenzia Spaziale Italiana, the Italian space agency, is contributing the 4-meter-diameter high-gain antenna and large portions of three orbiter science experiments.

MAGELLAN

In May, the Venus-orbiting Magellan spacecraft completed its fourth cycle of observations, in which high-resolution gravity data were obtained over the planet's equatorial regions. Precise tracking of the spacecraft's position provides a means of correlating features on the surface to concentrations of internal masses. Magellan data showed that, unlike Earth's development, the formation of Venusian surface features is strongly linked to fluid motions in the planet's mantle.

To obtain high-resolution gravity data near the poles, Magellan was moved from an elliptical orbit to a low-altitude, nearly circular orbit. Over several months, the flight team changed the orbit by employing a technique called aerobraking, which made use of the small amount of drag created as the spacecraft skimmed the atmosphere in each orbit. To alter the orbit through conventional means would have

required about 900 kilograms of propellant — almost 10 times as much propellant as was available on board the spacecraft. Variations in Venus' atmosphere and gravity field required that orbit corrections be made every four to nine days. The current orbit, which ranges in altitude from about 200 to 540 kilometers, allows high-resolution gravity data to be gathered over intriguing areas such as the highlands of Ishtar Terra, where Maxwell Montes, the highest mountain on Venus, is located.

TOPEX/POSEIDON

Working with the first year of data from TOPEX/POSEIDON — the satellite generates global maps of Earth's oceans every 10 days — an international team of scientists has begun to analyze the spaceborne altimetry data and to incorporate these data into computer models of ocean circulation. The ocean models will eventually be coupled with atmospheric models to lay the foundation for climate predictions.

Employing data acquired by TOPEX/POSEIDON, mission scientists expect to be able to provide much better forecasts of weather events. In 1993, for example, data from the oceanographic satellite showed that a fading El Niño event — an irregular shift in Pacific Ocean currents caused by a weakening of the tropical trade winds — had lingered on, boosted by a huge pulse of warm water (a Kelvin wave) that had been traveling across the tropical Pacific for months. Climatologists have linked this late surge of the El Niño with the fierce winds and deep snow drifts of the East Coast blizzards and the unrelenting rains in California that occurred this year.

The key to the mission's success is in combining TOPEX/POSEIDON's radar altimetry — which measures the height between the sea surface and the satellite — with precise orbit determination. Three independent tracking systems are used: the NASA laser-ranging system; the French Doppler Orbitography and Radioposi-

tioning Integrated by Satellite (DORIS) system that measures Doppler shifts from ground transmissions, and the U.S. Air Force's Global Positioning System. Combined, these systems track TOPEX/POSEIDON with an accuracy of 4 centimeters — three times better than the goal of the project, which is a joint effort of NASA and France's Centre National d'Études Spatiales.

MARS OBSERVER

In August, during final preparations to place the Mars Observer spacecraft in orbit about the Red Planet, communications with the spacecraft failed to resume after a scheduled interruption. Recovery efforts over the next two months proved unsuccessful. In response, the NASA Administrator appointed a Failure Review Board, and investigative groups were convened by JPL and by the spacecraft's developer, Martin Marietta Astro-Space. The reports of these groups were due late in the year.

The Mars Observer mission was developed to provide global reconnaissance of the planet Mars from a low circular orbit over a full Martian year (687 Earth days). Launched in September 1992, the spacecraft carried seven scientific instruments for studying Mars' surface and atmosphere. An image of the planet returned from the spacecraft in July showed extraordinarily clear atmospheric conditions.

Studies are being conducted to determine the most appropriate way to return orbiting spacecraft to Mars and to fulfill the objectives of the Mars Observer mission by using the launch opportunity in 1996 and perhaps the one in 1998.

MARS ENVIRONMENTAL SURVEY PATHFINDER

Mars Environmental Survey (MESUR) Pathfinder received an official project start in fiscal year 1994. The project, with a

firm cost cap of \$150 million, will primarily demonstrate a low-cost method of delivering payloads, such as scientific equipment, to the surface of Mars. Launch is scheduled for December 1996, with a landing on Mars in July 1997.

After it arrives at Mars, the MESUR Pathfinder lander will be parachuted through the thin atmosphere; as it nears the surface, small retrorockets will fire and airbags will inflate to cushion the impact of landing. Once the lander is on the surface, its petals will open to expose the solar panels and science instruments for engineering, technology and science investigations. In addition, the lander will deploy a micro-rover based on JPL's Rocky 4.3 design to explore the local terrain.

To meet the accelerated schedule, the project's flight system, rover, ground data system, science instruments and mission operations system are being designed concurrently. Each subsystem will be implemented and integrated, and its capabilities demonstrated, in phased deliveries about six months apart. The first incremental delivery was completed in 1993, and the second increment is well under way.

ULYSSES

In June 1993, the Ulysses spacecraft passed below 32.4 degrees south solar latitude, surpassing Voyager as the spacecraft farthest from the Sun's equator. The project is preparing for high-latitude operations, which will begin when Ulysses reaches 70 degrees south solar latitude in June 1994. The spacecraft will reach a maximum latitude of 80 degrees in September 1994.

Ulysses, a joint project of NASA and the European Space Agency, has already acquired significant scientific data. Among Ulysses' recent discoveries are evidence of latitude gradients in the magnetized solar wind; the first direct detection of neutral helium arriving from interstellar space; the identification of periodic dust streams

from Jupiter and interstellar dust grains; the first measurement of singularly charged ions entering the heliosphere as interstellar neutral atoms and then becoming ionized; the first detection of ion cyclotron waves associated with pickup ions; the highest resolution measurements to date of the isotopic composition of cosmic-ray nuclei, and the detection of hundreds of gamma-ray bursts.

VOYAGER

Sixteen years after launch, the two Voyager spacecraft continue their search for the heliopause — the region where the Sun's magnetic influence wanes and interstellar space begins. The onboard plasma wave science instruments continue to detect radio waves believed to have been triggered at or near the heliopause by a large disturbance in the solar wind that originated during a period of intense activity on the Sun in late May or early June 1991.

Both spacecraft remain in good health, and all instruments needed to study interplanetary space continue to operate satisfactorily. The Voyagers have enough electrical power and thruster fuel to operate for another 20 to 25 years.

U.S. SPACE VERY LONG BASELINE INTERFEROMETRY

The Space Very Long Baseline Interferometry (Space VLBI) missions, Radioastron (Russia) and VLBI Space Observatory Program (Japan), will produce radio images of celestial objects with unprecedented resolution — up to 10 times better than the best ground-based radio VLBI images and 1,000 times better than the best optical-ultraviolet images from the repaired Hubble Space Telescope.

This year, the U.S. Space VLBI project's Science Support Team, sponsored by NASA and staffed by JPL, continued to critically study the scientific productivity of the missions, to identify flaws in the



missions' designs and to suggest methods for better meeting the missions' science objectives. By simulating all scientific aspects of the missions, the team has made several contributions to improving mission design for both the Radioastron and VLBI Space Observatory Program spacecraft.

Because the Space VLBI missions require simultaneous observations by ground radio observatories, another major effort supported by JPL involves negotiations for observing time on independent ground radio telescopes around the world. Advanced technology is being investigated to put larger (and possibly inflatable) antennas into space for a follow-up mission of even greater sensitivity.

FLIGHT SYSTEM TESTBED

JPL has developed a new test facility to help researchers create the high-technology, smaller spacecraft required for future exploratory missions. The aims of the Flight System Testbed are to reduce costs, shorten schedules, identify and resolve problems early and mitigate the risks associated with spacecraft and mission development.

JPL designers — employing a virtual-spacecraft approach that simulates instruments, sensors and subsystems — will use the testbed for system-level, concurrent development of the entire spacecraft along with its ground data system. This approach makes possible rapid spacecraft prototyping, allowing components at varying levels of development to be tested as part of an en-

The Mars Observer spacecraft

captured this view of the Red Planet from a distance of 5.8 million kilometers in 1993. JPL is planning a return mission to explore Mars.

tire system. The testbed will also be used to compare the performance of alternate subsystem designs as they function at the system level, making it possible to identify interface problems long before the spacecraft is built.

Pluto Fast Flyby will be the first mission to use the new facility, beginning in January 1994. In addition, the Microspacecraft Development Program will use the testbed to evaluate innovative architectures for spacecraft subsystems, paving the way for future miniaturized deep space probes.

ADVANCED MISSION STUDIES

PLUTO FAST FLYBY

A development team is designing a mission to send two very small spacecraft to Pluto and its moon Charon. The two probes, each carrying four science instruments, would obtain data on both hemispheres of Pluto and Charon in visual, infrared, ultraviolet and radio wavelengths. The goal is to reach Pluto well before the planet's atmosphere collapses and the planetary system sinks deeper into long-term seasonal shadow. Cost, schedule and performance are the primary design concerns.

During 1993, NASA sponsored an advanced technology insertion effort involving industry, academia and other government centers in gathering ideas to reduce the mass of the Pluto Fast Flyby spacecraft. Contracts and agreements were established with numerous partners to fab-

ricate components and test technology. Overall, the spacecraft mass was reduced by 45 kilograms, enabling a shorter flight time to Pluto. In addition, a number of contracts and agreements were made with universities to gather new ideas and involve students; as a result, over 50 students from 20 institutions have made significant contributions to the spacecraft development.

Also in 1993, the science instrument teams began to breadboard their instruments to prove that low-mass, low-power payload concepts are achievable.

MARS SAMPLE RETURN

A Mars sample-return mission was studied in 1993. It could be launched as early as 2003 with a total cost cap (including development, launch services and mission operations) of \$1 billion. A flight system design, developed by Martin Marietta, would return half a kilogram of Martian rock and soil samples using a microrover, a Mars ascent vehicle and a separate spacecraft to return the sample to Earth.

NEAR-EARTH ASTEROID: SAMPLE-RETURN CONCEPTS

Under consideration is a mission to collect a small — 50-gram — sample from the surface of a near-Earth asteroid and return the sample to Earth. The mission concept requires a 30-day asteroid rendezvous. Several spacecraft options have been developed along with mission opportunities for 1995 through 2005.

ASTEROID, COMET, MOON EXPLORER

A concept has been developed for a series of small spacecraft, each with focused science objectives and a total cost (from inception through end of mission) of \$75 million or less. As part of the "Asteroid, Comet, Moon Explorer" concept — so named to denote possible targets — the spacecraft would be launched by Pegasus-

class launch vehicles. A single failure would result in the loss of only a single spacecraft out of a series of missions, thereby enabling more frequent launches. Cutting-edge technologies — lightweight attitude sensors, composite structures, very low power electronics and solar electric propulsion — are under consideration.

SPACE INFRARED TELESCOPE STUDIES

JPL's space infrared telescope activities are aimed at the definition and eventual construction, launch and operation of telescopes for spaceborne infrared astronomy. During 1993, JPL continued management of a technology and engineering development program for more sensitive infrared detectors and detector arrays. This program primarily comprises three university-based teams working closely with industrial subcontractors. In addition, JPL has worked with NASA and the science community to develop new, lower cost mission concepts that are now under evaluation.

SATELLITE TEST OF THE EQUIVALENCE PRINCIPLE

A basic postulate of Einstein's General Theory of Relativity states that a body's gravitational mass (a property of a body under gravitational attraction) is equivalent to its inertial mass (a property of a body in motion). The Satellite Test of the Equivalence Principle, a joint NASA-Stanford University project, would test this postulate with unprecedented precision: one million times more accurately than previous experiments. In 1993, the project design matured; the mission is now in Phase A studies with the goal of a NASA new start in 1996 and a launch into Earth orbit three years later.

ASTROMETRIC INTERFEROMETRY

The Astrometric Interferometry Mission, which could be launched early in the next century, would fix the position of astrophysical objects with unprecedented accu-

racy. Space laser metrology systems are being designed to measure the geometry of the mission's optical interferometer to approximately one picometer, which is a millionth of a millionth of a meter. The past year was marked by the development of significantly lower cost mission and flight-system designs that retain most of the scientific goals.

SUBMILLIMETER INTERNATIONAL MISSION

The Submillimeter International Mission would survey our galaxy just beyond the infrared wavelength — leading to a better understanding of the physics and chemistry of the massive structure within which our Sun and system of planets are embedded. The mission goal is to launch early in the next century in collaboration with international partners. World-class electronic and optical systems are being developed to support the scientific payload. In particular, significant progress was made in 1993 toward developing a heterodyne receiver that can operate at terahertz frequencies.

OTHER ASTROPHYSICS AND FUNDAMENTAL PHYSICS CONCEPTS

A gravity-wave mission — the Laser Interferometer Space Antenna — is being evaluated jointly by NASA and the European Space Agency. Once detected, gravity waves are expected to provide a channel of information parallel to the more familiar electromagnetic waves.

Subtle and slight variations in the cosmic background radiation are thought to be the precursors of the galaxies that populate space in our cosmic era. Two missions, the Far Infrared Experiment and the Primordial Structure Investigation, are being developed to characterize these variations with greater detail and gain an understanding of the state of the early universe.

Einstein's prediction of the bending of light by the gravity of massive objects would be tested to an unprecedented de-

gree of precision by the Laser Astrometric Test of Relativity. The test would involve shining laser "flashlights" from beyond the Sun to observers on Earth.

MULTIMISSION OPERATIONS

The Multimission Operations Systems Office (MOSO) now provides multimission tools, services and processes for nearly all elements of mission operations. During 1993, MOSO continued to provide simultaneous support to the Magellan, Mars Observer, Ulysses and Voyager projects using the advanced multimission operations system (AMMOS); MOSO supported the Galileo project using the old mission control and computing center system while working to complete a transition to the AMMOS. MOSO also provided major support to the Cassini project and worked closely with several preproject studies.

This year, the Multimission Control Team was fully established with all controllers now certified to support at least two flight projects, and many to support three. The Multimission Navigation Operations Team was formed to maintain and operate the Navigation Computing Facility. The navigation team, on a budget that is about 10 percent of what it would have cost to operate navigation software on the old Unisys 1100 computer, is providing a full range of navigation services that includes improvements in capability and performance.

Multimission planning and sequencing became a reality this year with the delivery of SEQTRAN, a sequence translation program. Operating on a UNIX workstation, this software tool provides significantly improved performance over the old main-frame-operated, single-mission method. MOSO has found that these multimission systems can help provide the low-cost, high-quality support needed for the new, smaller missions.

JPL shed new light on Earth and space

Conducting basic research and developing instruments for space exploration and the study of Earth and its environment, JPL adds significantly to knowledge of the planets, solar physics and astronomy. Activities in 1993 included generating, processing, analyzing, archiving and disseminating a variety of Earth and space science data to scientists, educators and the public.

Work this year provided insight into ozone-depleting processes in Earth's stratosphere and improved understanding of ocean circulation. Other efforts, using data from Earth-orbiting satellites and conventional techniques, expanded the ability to measure tectonic plate motion of the ocean floor; such

observations will lead to a global view of plate motion and the processes that can cause earthquakes.

JPL completed a number of flight instruments, including the Wide Field/Planetary Camera 2, which has already compensated for the distortion in the Hubble Space Telescope primary mirror, and the Spaceborne Imaging Radar-C/X-Band Synthetic Aperture Radar, which will measure Earth's biomass and soil moisture on a global scale.

Also during 1993, collaborative radar observations obtained views of Mars' northern polar region, and JPL began using the SR-71 Blackbird aircraft to support a range of scientific experiments.



Once a spy plane, the SR-71 Blackbird is now a platform for science investigations like JPL's near-ultraviolet spectrometry studies.

EARTH SCIENCE

SPACEBORNE IMAGING RADAR

A giant, multiple-frequency sensor known as the Spaceborne Imaging Radar-C/X-Band Synthetic Aperture Radar (SIR-C/X-SAR) was integrated, environmentally tested and shipped to the NASA Kennedy Space Center this year in preparation for the instrument's first flight aboard the space shuttle in spring 1994. A second flight is scheduled during the summer of 1994. In orbit, the SIR-C/X-SAR imaging sensors will collect data on Earth's carbon, water and energy cycles and study the human impact on these cycles.

In preparation for the mission, the SIR-C/X-SAR science team completed the planning for data acquisition, crew activities, space shuttle maneuvers, flight science activities and field activities. Airborne synthetic aperture radar data were obtained over planned SIR-C/X-SAR sites in Central America and Australia.

The project is a joint venture of NASA, the German space agency (Deutsche Agentur für Raumfahrtangelegenheiten GmbH) and the Italian space agency (Agenzia Spaziale Italiana), with 52 science investigators from around the world. The instrument integrates the NASA-developed SIR-C, an electronically scanned array of L-band and C-band radars, with an X-band radar built by the German and Italian space agencies. This combination of multiple-frequency, multiple-polarization radars makes possible far more detailed assessments of global phenomena from space than were possible with earlier spaceborne radars.

SIR-C/X-SAR FREE FLYER

As an alternative to a third SIR-C/X-SAR flight aboard the space shuttle, or following a third flight, an Earth-orbiting version of the radar system — the "free flyer" concept — has been proposed. Such a free

flyer promises to greatly increase the science returns possible with the sensor, approaching those projected for the future NASA Earth Observing System's synthetic aperture radar mission, but at a greatly reduced cost and at relatively low risk.

The data return from a SIR-C/X-SAR free flyer would be extraordinarily large, potentially producing about 1.5 terabits per day of multiple-frequency, multiple-polarization radar data. During the first 107 days, 67 percent of Earth's land mass between the latitudes of 57 degrees north and south could be mapped. During the second 107-day period, 98-percent coverage could be obtained. The free flyer is designed for a two-year mission, so the mapping process can be repeated several times to monitor temporal and seasonal changes on a global scale.

MICROWAVE LIMB SOUNDER

New insights into the problem of ozone depletion have been provided by daily global measurements of ozone, temperature and chlorine monoxide. For more than two years, the Microwave Limb Sounder flying on NASA's Upper Atmosphere Research Satellite has supplied a nearly continuous data record of stratospheric composition, chemistry and dynamics to help scientists who are studying threats to Earth's protective ozone layer. This instrument is an earlier version of the one planned for NASA's future Earth Observing System — a series of satellites that will provide a global survey of Earth's surface and atmosphere.

The Microwave Limb Sounder is unique in its ability to monitor and map global concentrations of chlorine monoxide, the key chemical agent in the catalytic destruction of ozone. Wintertime polar stratospheric clouds cause an increase in chlorine monoxide concentrations that leads to the formation of the springtime Antarctic ozone hole. An influx of ozone-rich air counteracts the destructive properties of the enhanced chlorine monoxide

levels for much of the time — the southern hemisphere ozone hole only forms at the end of the annual cycle when chemical processes outweigh dynamic effects.

In the northern hemisphere winter, enhanced chlorine monoxide concentrations exist over a similarly sized polar area, but for a shorter period of time than is needed to create a deep Arctic springtime ozone hole. There is, however, considerable year-to-year variability in the length of time cold stratospheric air persists, and northern polar ozone depletion continued for much longer in 1993 than in 1992. Microwave Limb Sounder observations have added a global perspective on the record low ozone readings reported in spring 1993 by responsible agencies throughout Europe and North America.

ATMOSPHERIC INFRARED SOUNDER

The Atmospheric Infrared Sounder (AIRS) — a high-resolution array spectrometer incorporating advanced cryogenic coolers and very sensitive magnesium cadmium telluride infrared detectors — is scheduled to fly on the NASA Earth Observing System in 2000. Loral Corporation and JPL have successfully extended the range of sensitivity of the AIRS detector arrays beyond the current limit of 13 micrometers.

AIRS will make simultaneous observations of Earth's atmospheric, ocean-surface and land-surface temperatures, as well as humidity, clouds, surface albedo (a measure of how much light is reflected from Earth's surface) and the distribution of greenhouse gases. This makes AIRS the primary Earth Observing System instrument for monitoring climate variations and trends, detecting the effects of increased greenhouse gases and studying global energy and hydrology cycles. AIRS is also intended to become an element of the National Oceanographic and Atmospheric Administration's future weather satellite system and will provide accurate weather forecasts for seven- to ten-day periods.

MULTI-ANGLE IMAGING SPECTRORADIOMETER

JPL and Loral Corporation have jointly developed an improved version of the charge-coupled-device image detectors used in the Multi-Angle Imaging Spectroradiometer (MISR), which will study the effects of geophysical processes and human activities on Earth's ecology and climate as part of NASA's Earth Observing System program. The improved detector is sensitive to blue light, one of the four colors required for MISR imaging. Previous methods for obtaining blue-light sensitivity had proved expensive and difficult to implement.

In another development milestone, JPL and Labsphere have jointly conducted tests to demonstrate that a Labsphere-developed diffusion material — a form of sintered polytetrafluoroethylene called Spectralon — is suitable for use in space. Such material is needed to maintain the highest level of accuracy in MISR measurements. MISR will be calibrated periodically in flight using direct sunlight scattered from an onboard diffuser. Spectralon has the best optical properties for this application, but its stability in the space environment had not been measured before. Testing on outgassing, exposure to ultraviolet radiation, thermal expansion, high- and low-temperature survival and electrostatic charging confirmed that the material has sufficient optical stability to meet mission requirements.

ATMOS ON ATLAS-2

The Atmospheric Trace Molecule Spectroscopy (ATMOS) instrument was successfully flown in April on the second in a series of space shuttle missions designated the Atmospheric Laboratory for Applications and Science (ATLAS). Previously flown on Spacelab 3 in 1985 and on ATLAS-1 in 1992, the instrument is part of the core payload for ATLAS, which is studying the complex relationships be-

tween the Sun and Earth's atmosphere. These measurements will increase in importance during the period between the deployments of the Upper Atmosphere Research Satellite and the Earth Observing System as ATMOS becomes a primary instrument for monitoring atmospheric chlorine species as well as the greenhouse-gas molecules.

In a rare departure from standard space shuttle procedure, ATLAS-2 was launched in early morning darkness. This early launch time provided an orbit that allowed the ATMOS instrument to make atmospheric measurements at high northern latitudes for the purpose of studying seasonal polar ozone depletion. In addition, ATMOS made observations on numerous occasions in near proximity to the Upper Atmosphere Research Satellite. These measurements can be correlated with those made by several of the satellite's instruments — including the NASA Langley Research Center's Haloe sensor and JPL's Microwave Limb Sounder — providing important calibration data for the satellite payload.

The data acquired by ATMOS during the ATLAS-2 flight have the potential for providing new insights into the annual polar ozone processes as well as for assessing long-term and seasonal changes occurring in the atmosphere on a global scale. The reduction and analysis of the flight data are continuing.

MEASUREMENT OF OCEAN-FLOOR TECTONIC PLATE MOTION

For several years, the Global Positioning System (GPS) network of Earth-orbiting satellites has enabled geologists to observe tectonic plate motion with an accuracy of a few millimeters per year on intercontinental baselines, using land-based reference points. However, the vast majority of active tectonic sites, including plate boundaries and spreading centers, lie under the oceans, hidden from direct measurement.

Thus, obtaining a comprehensive global understanding of plate motion — and the processes that underlie it — requires the development of methods for observing underwater sites and bringing them into the existing terrestrial reference frame.

In August and September, an interdisciplinary team from JPL and several other institutions measured tectonic plate motion of the ocean floor, using a floating platform that combines GPS technology with conventional acoustic methods for underwater positioning. Above the platform's water line are three GPS antennas used to determine the location and orientation of the platform. Below the platform's water line is an acoustic transducer that transmits signals to and receives answering signals from an array of long-lived transponders that has been placed on the ocean floor. Together, the GPS and acoustic measurements make it possible to determine the location of an ocean-floor reference point and, over a period of years, to measure its motion with respect to terrestrial reference points.

Measurements were made at an ocean-floor site on the Juan de Fuca Plate, near its boundary with the North American Plate, about 150 kilometers west of the Olympic Peninsula. This site is particularly interesting because the rate of convergence of the two plates is fairly rapid (about 44 millimeters per year), and because of the potential for disastrous earthquakes as the plates grind past one another beneath the densely populated Seattle, Washington, region.

Initial measurements had been made in May-June 1991; at that time, four transponders were positioned on the ocean floor at a depth of about 2,600 meters. Analysis of the data indicates that the estimated location of the transponder array is accurate to a few centimeters, relative to the GPS sites on Vancouver Island. For this year's measurements, two more transponders were deployed, and an improved platform collected data for three days. Future site measurements will give increasingly precise estimates of the relative

motion of the two plates and will help geologists to discriminate among competing models of the interaction at the plate boundary.

SEA-SURFACE TEMPERATURE MEASUREMENTS

A precision infrared multichannel radiometer developed by JPL for NASA was mounted in the cargo bay of the National Center for Atmospheric Research's Electra 308D aircraft and flown over the equatorial Pacific ocean during an international climate experiment called the Tropical Ocean Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA COARE). TOGA COARE was designed and implemented to measure and model thermal interactions between the atmosphere and sea surface in the western Pacific "warm pool," a region as large as the United States with the highest temperature and the most intense atmospheric convection (vertical atmospheric motions and mixing) anywhere in the open ocean.

This research program — which will improve the forecast of El Niño phenomena (irregular shifts in Pacific Ocean currents caused by a weakening of the tropical trade winds) — involved the efforts of over 1,000 people, 14 research ships, 7 research aircraft and several satellite observing systems. During the period November 1992-February 1993, high-precision temperature measurements were obtained from the airborne radiometer simultaneously with direct atmospheric flux measurements of heat and moisture. Multispectral observations in the 10- to 12-micrometer infrared region were made to improve understanding of the radiative and dynamic processes that influence sensible heat transfer and evaporation in the marine boundary layer, and to assess radiative temperature effects related to water vapor gradients and downwelling longwave emission from clouds.

Additionally, during March 1993, the instrument flew on 5 Electra missions in support of the Central Equatorial Pacific

Experiment (CEPEX), a program to study the effects of cirrus clouds on the regulation of sea-surface temperatures.

The data obtained from the radiometer will determine the accuracy requirements of spaceborne infrared sensing systems designed to measure temperature over the tropical ocean. Results show extremely high absorption of outgoing sea-surface radiation by atmospheric water vapor within the lowest 2 kilometers of the atmosphere.

EARTH SCIENCE INSTRUMENT DEVELOPMENT

In 1993, the Jet Propulsion Laboratory began evaluating and developing the premier spy plane of the Cold War, the SR-71 Blackbird, as a new scientific research platform. With its significant capabilities of high-altitude (26,000-meter) flight, extensive geographical coverage, quick response time and large payload areas, the SR-71 offers significant research potential in a wide variety of scientific disciplines.

The following experiments were conducted by a JPL team working with the NASA Dryden Flight Research Facility team that operates the aircraft. The Southwest Research Institute's Ultraviolet Imaging System, which is being evaluated for use in solar system studies, successfully collected images in a variety of lighting conditions at altitudes above 24,000 meters. A Near-Ultraviolet Spectrometer, designed and built at JPL, was flown on six flights. The instrument employs downward- and upward-looking optics to study such phenomena as volcanic plumes and ozone abundances. The Dynamic Auroral Viewing Experiment, created by the University of California, Los Angeles, consists of a set of upward-viewing ultraviolet and infrared photometers mounted in the aircraft nose. Flights at sundown and at night permitted the photometers to make observations of auroral emission. The NASA Commercial Experiment Transporter program's low-

Earth-orbit experimental communications satellite, built by Motorola, was flight-tested as part of a checkout prior to space launch.

PLANETARY SCIENCE

TOWARD OTHER PLANETARY SYSTEMS

Toward Other Planetary Systems, a program aimed at detecting other planets beyond Earth's solar system, has both an initial ground-based component and a later space-based component. Over three years, the ground-based effort will design, develop, construct and operate a testbed interferometer that is intended to be the precursor of a large interferometer constructed around the twin Keck Observatory telescopes in Hawaii.

This 100-meter-long baseline testbed interferometer is unique in several ways. It incorporates a new technique called "phase closure" to obtain much higher resolution than has previously been possible by taking advantage of not only the amplitude of the interfered signal, but its phase component as well. The testbed makes use of another new technique called "narrow-angle astrometry," which utilizes two adjacent stars in the same field of view. This will be done in the near-infrared, 2.2-micrometer

wavelength to take maximum advantage of both the atmospheric qualities at this frequency and the properties of the Keck Observatory.

The testbed interferometer will be located adjacent to the Mount Palomar 5-meter telescope. When complete, the testbed is expected to demonstrate high-sensitivity infrared direct detection; measurement of the astrometric limit for a long-baseline infrared system, and systematic errors in the range of 60 to 100 microarcseconds. Demonstration of the phase-closure technique will result in systematic errors that are expected to be less than 1/200 of the wavelength of light used. These capabilities should enable the interferometer to detect a Jupiter-sized planet around a solar-type star (one like Earth's Sun) 33 light years away in a four-year observing program.

RADAR OBSERVATIONS OF MARS

In early 1993, several radar observations of Mars were performed using signals transmitted from the Deep Space Network's 70-meter antenna at Goldstone in Southern California's Mojave Desert, and received by the National Radio Astronomy Observatory's Very Large Array in Socorro, New Mexico. These radar im-

ages provided the first look at the northern polar region of the planet at a 3.5-centimeter wavelength.

In contrast to Mars' very radar-bright southern polar cap (probably composed of ice), which was discovered two years ago by the Goldstone radar, the northern cap has only a few small areas of bright reflection. One possible explanation for this difference is that the northern polar cap is composed of ice that contains large amounts of dust particles. The large, radar-dark (radar-absorbing) region known as "Stealth" was also confirmed in this year's observations. This feature is probably composed of a vast deposit of radar-absorbing material that stretches westward for thousands of kilometers from the planet's Tharsis volcanic area.

ASTROPHYSICS AND SPACE PHYSICS

WIDE FIELD/PLANETARY CAMERA 2

In December, as part of the first servicing mission to the Hubble Space Telescope, the Wide Field/Planetary Camera 2 was launched on the space shuttle and successfully installed in the telescope. The new camera replaced the original instrument launched with the Hubble in 1990. In-orbit verification and optical alignment were performed, enabling the telescope to acquire science images ahead of schedule. These images verified that the new camera has completely restored the Hubble's imaging capability, which had been impaired by a spherical aberration in the telescope's main mirror.

This year, JPL personnel participated in extensive simulations to refine camera-installation techniques with the astronauts assigned to the telescope-servicing mission. Assembly and testing of the Wide Field/Planetary Camera 2 was completed, and the camera was delivered ahead of schedule to the Hubble Space Telescope project at the NASA Goddard Space Flight Center,

where final compatibility testing was conducted. The camera was then shipped to the NASA Kennedy Space Center, where it was integrated into the payload carrier and installed in the space shuttle prior to launch.

PREPARATIONS FOR COMET IMPACT ON JUPITER

The Shoemaker-Levy 9 comet, discovered in late March 1993, has been described as "pearls on a string." Observations indicated that the "string" had passed only 40,000 kilometers from Jupiter's cloud tops in July 1992, implying that it had been a single object until shattered by Jovian tidal forces. In May, JPL announced that the fragments would hit Jupiter's night side, about 40 degrees south of the equator, during the comet's next passage through the Jovian system in July 1994.

The collisions are expected to release a total energy that would dwarf the explosive capability of Earth's entire nuclear arsenal. JPL researchers are coordinating with observatories throughout the world to help maximize the unique opportunity for scientific study and public education offered by these huge impacts.

Although the impacts will occur on Jupiter's far side, as observed from Earth, the planet's rotation rate is sufficiently fast to allow views from Earth about two hours after the events occur. Scientists expect most of the twenty-odd largest fragments to penetrate well below the visible cloud decks before they explode, each depositing most of its energy in atmospheric levels not visible from Earth. This immense release of energy should heat a vaporized comet fragment and a large volume of local atmosphere into searing incandescence, spawning a huge fireball that will rise and cool. Most of the lower atmosphere materials carried in the fireball will eventually condense in Jupiter's stratosphere, where they will be visible from Earth.

*S*cheduled to fly on ATLAS-3 in 1994, the Active Cavity Radiometer will measure the radiant energy of the Sun in studies of Sun-Earth climatic interactions.



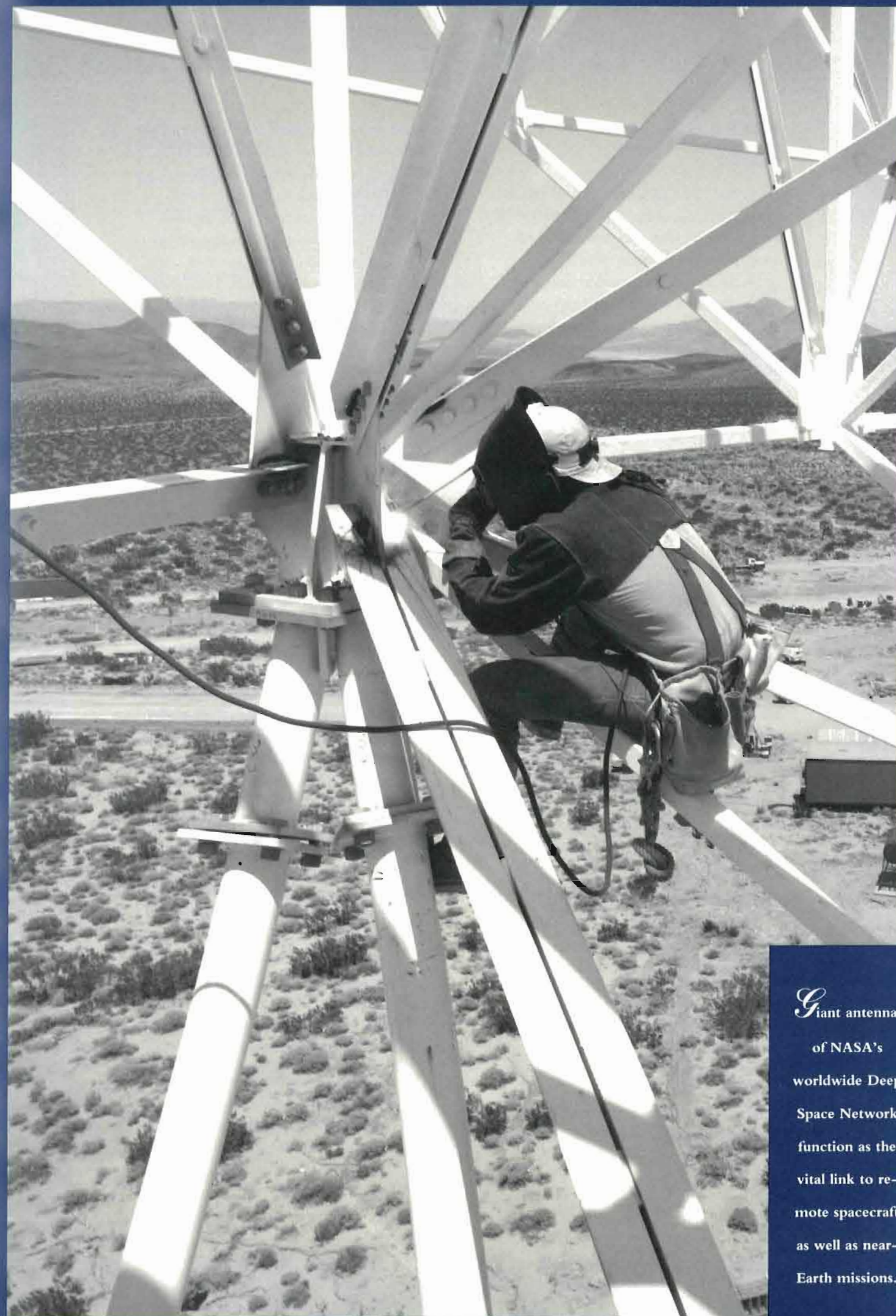
The DSN tracked 29 space missions

The Deep Space Network (DSN), NASA's worldwide system for communicating with spacecraft above low Earth orbit (about 15,000 kilometers), is managed by JPL through the Telecommunications and Data Acquisition Office. The DSN also tracks Earth-orbiting spacecraft not supported by NASA's Tracking and Data Relay Satellite System.

The DSN's three Deep Space Communications Complexes — at Goldstone, California, near Madrid, Spain, and near Canberra, Australia — are separated by approximately 120 degrees of longitude so that a distant spacecraft is normally in view of one of the stations. The

Network Operations Control Center at JPL directs the operations of each complex.

During 1993, the DSN provided communications and tracking for 29 deep space and near-Earth missions: JPL-managed Galileo, Magellan, Mars Observer and Voyager; other NASA spacecraft, and several European and Japanese projects. The DSN performed radio-science observations at all three complexes as well as radar observations from Goldstone that included joint efforts with the National Radio Astronomy Observatory's Very Large Array, a system of radio telescopes in Socorro, New Mexico.



*G*iant antennas
of NASA's
worldwide Deep
Space Network
function as the
vital link to re-
mote spacecraft
as well as near-
Earth missions.

MISSION SUPPORT

GALILEO

In August, the DSN supported the Galileo spacecraft's encounter with the asteroid Ida. DSN tracking time was provided in advance of the encounter to enable the acquisition of optical navigation data. These data, together with radio navigation data generated directly by the DSN, allowed engineers to plot Galileo's course. At Ida, the spacecraft was repositioned to point its camera at the asteroid. Since this maneuver pointed the spacecraft's low-gain communications antenna 28 degrees away from Earth — further degrading a communications link already impaired by the unavailability of Galileo's high-gain antenna — the DSN provided continuous 70-meter antenna coverage using a receive-only mode. This coverage allowed Ida data from Galileo to be recovered at a rate of 10 bits per second.

MARS OBSERVER

The DSN provided communications and tracking for Mars Observer during the spacecraft's cruise to the Red Planet. Continuous antenna coverage was supplied in late June in preparation for the insertion of the spacecraft into Mars orbit. Coverage continued until the spacecraft's transmitter was turned off in August as planned to allow Mars Observer to pressurize its fuel tanks in preparation for the orbit-insertion maneuver. Communications with the spacecraft failed to resume after this scheduled interruption.

Immediately calling its 70-meter antennas into service, the DSN searched for a Mars Observer signal for several days. During this period, the research and development antenna at Goldstone was added to the search, along with the antenna's ultra-sensitive electronic equipment — including the High-Resolution Microwave Survey's

spectrum analyzer and a multifrequency receiver known as the Experimental Tone Tracker. After one week, the DSN attempted to transmit to the spacecraft a command sequence to activate the on-board 432-megahertz beacon that was to have been used in conjunction with a future Russian mission to Mars. The Goldstone 70-meter antenna was modified to receive this frequency and relay any acquired signals to the research and development antenna for processing. After three days of searching for the beacon produced no results, the 70-meter antenna was returned to operation for other missions. The DSN continued to conduct an almost daily search for Mars Observer's signal for the rest of the year.

MAGELLAN

In May, the Magellan spacecraft successfully completed its fourth full revolution around Venus (each requires eight Earth months), in which it mapped the planet's gravity field using data generated by the DSN's sensitive Doppler radio-metric data system. To improve the resolution at high Venusian latitudes, the spacecraft was moved in an aerobraking procedure from an elliptical orbit to a more circular orbit. The DSN supported this procedure with rapid data acquisition after each excursion through the atmosphere in order to check the spacecraft's new position. Also, the continuously changing orbit required daily updates to the pointing predictions provided to the DSN antennas. The DSN met these challenges and subsequently began generating high-resolution gravity data for all Venusian latitudes.

TOPEX/POSEIDON

The DSN made extensive use of the U.S. Air Force's Global Positioning System (GPS) in a highly successful demonstration of precision orbit determination involving

Powerful Deep

Space Network
antennas, dedicated
to the scientific in-
vestigation of the
planets and inter-
planetary space,
track spacecraft fly-
ing throughout the
solar system.



the TOPEX/POSEIDON satellite, which is studying Earth's oceans. GPS comprises a network of Earth-orbiting satellites transmitting beacon signals. The signals from these satellites can be used to determine the positions of the GPS satellites themselves and any observer equipped with a GPS receiver. A GPS receiver is located aboard TOPEX/POSEIDON and other receivers are located at each of the three DSN complexes. In addition, GPS receivers were installed in Chile (with the University of Chile), South Africa (with the Centre National d'Études Spatiales) and Japan (with the Institute of Space and Astronautical Sciences), resulting in a six-receiver GPS global ground network.

All the receivers operate continuously and automatically. The data from the sites are transmitted to JPL where they are merged with the data from the TOPEX/POSEIDON receiver and processed to ascertain the oceanographic satellite's position. Orbit-determination accuracies of 1 meter were expected. In fact, TOPEX/POSEIDON's position was able to be

determined from the GPS data with an accuracy of less than 5 centimeters. An accuracy of 10 centimeters or less is required for the satellite to make precise measurements of sea-surface height. As a result, the TOPEX/POSEIDON project decided to continue GPS operations for the remaining two years of the satellite's primary mission.

NETWORK UPGRADES AND NEW CAPABILITIES

FACILITY LIFE EXTENSION

The DSN's 70-meter antennas are in increasing demand as NASA's planetary spacecraft become smaller and travel farther from Earth. To ensure that these antennas remain fully operational, the DSN has begun a life-extension program that includes upgrading gear boxes and major bearings. This year, the upgrades have been accomplished at Goldstone and Canberra. Since the antennas cannot be used for spacecraft tracking during this maintenance, parts of the antenna electronics are being upgraded

at the same time — including a new cooling system for the high-power transmitters, rehabilitation of some of the microwave receiving feeds and some structural enhancements.

GALILEO MISSION ENHANCEMENTS

The DSN has begun enhancing its complexes to enable the Galileo mission to achieve its scientific objectives at Jupiter without the use of the spacecraft's high-gain antenna. Reception of the much weaker signal from Galileo's low-gain antenna will be improved by using new, more powerful, error-correcting codes. The DSN is also planning to combine the received signals from several of its antennas — a technique expected to be used within a DSN complex of antennas as well as between a pair of complexes. In addition, the 70-meter antenna at Canberra is being modified to increase its sensitivity. (The Canberra complex is expected to play the key role in supporting Galileo's Jupiter mission because the spacecraft will be in the southern sky during its Jovian tour.)

Also during the year, the DSN — using its antennas together with its research and development electronics — performed several important tests of Galileo's communication system in preparation for the spacecraft's Jupiter orbital mission in 1995. These tests demonstrated the feasibility of using a direct modulation technique that will triple Galileo's data transmission rate. Together, these improvements will result in a 10-fold increase in data returned from Galileo. A second 10-fold increase will result from the data compression enabled by these improvements, resulting in a 100-fold total increase.

BEAM-WAVEGUIDE ANTENNAS

Construction is progressing on a series of new 34-meter antennas that will help the DSN to meet the needs of NASA's future planetary missions. The new antennas, based on the design of the research and development antenna at Goldstone, are called beam-waveguide antennas because microwave energy that is incident on the dish is channeled by a large waveguide to a room beneath the antenna. The first such antenna is scheduled to begin operation at Goldstone in April 1994. Construction of the second and third antennas, also to be situated at the Goldstone complex, began in late 1993. These antennas are expected to become operational in early 1996.

DIGITAL RECEIVER

The DSN is building a new-generation receiver, called the Block V, using state-of-the-art digital technology. Prototypes of this receiver are being used at Goldstone's research and development antenna. The Block V will be able to track signals with about 16 times the data-rate capability of current receivers, allowing the DSN to serve its customers into the next century. Also, the Block V will be more sensitive, even at low data rates, than current DSN receivers, thus helping to enable the Galileo Jupiter orbital mission.

The heart of the Block V is a digital demodulator that uses five gallium arsenide computer chips. These chips, comprising three unique 1.2-million-transistor JPL designs, operate at 160 megahertz — about four times faster than the fastest current personal computers. They are the first production gallium arsenide chips of this size in any system. During 1993, the chips

were fabricated, then integrated into the Block V receiver. This new receiver will begin operation at DSN complexes in 1995.

ARCHITECTURE STUDIES

Long-range planning is critical for the DSN to maintain a high level of quality service for its customers well into the future. A software tool, originally written to assist in planning JPL's flight projects, has been adapted for DSN use. The tool models how user requirements could be met without having to generate detailed DSN schedules. The software can analyze the marginal impact of new missions or new DSN capabilities. This ability will allow the DSN to determine its future support capabilities before investing in new equipment and facilities, thus leading to potential cost savings. In a recent example, the tool suggested that DSN support of current missions is not as dependent on a geographically distributed set of antennas as has been the case in the past.

COMMUNICATIONS TECHNOLOGY

DATA COMPRESSION

Faced with the unavailability of Galileo's high-gain antenna for transmitting data once the spacecraft arrives at Jupiter, the Galileo project will use the technique of data compression to achieve its Jupiter science objectives with the spacecraft's operational low-gain antenna. A new algorithm, called the Integer Cosine Transform, has been adapted for use on Galileo imaging data. It is similar to the international standard for image compression, but requires much less computation so it can be placed into Galileo's small onboard flight computer. Analysis using Galileo images has

been employed to tailor the algorithm to the spacecraft and to predict how much compression will occur in practice. Also, software for the algorithm has been written for the Galileo flight computer. Decompression algorithms are being developed and will be installed as part of the Galileo ground system. The new algorithm will result in an increase of a factor of about 10 in data returned from the mission.

KA-BAND COMMUNICATIONS

As part of its communications system, Mars Observer carried an extra antenna designed to transmit at Ka-band (34 gigahertz). Mars Observer began transmitting at Ka-band in January 1993 — the first use of this frequency from deep space — as part of the Ka-Band Link Experiment, which had been five years in the planning. For two weeks, the faint Ka-band signal — 1,000 times weaker than Mars Observer's main communications link at X-band (8.4 gigahertz), the standard DSN communications frequency — was tracked by the Goldstone research and development antenna. Despite some of the worst weather in many years, data were received at 250 bits per second. In February, a second set of Ka-band observations demonstrated the utility of this frequency for measuring the distance between a ground station and a spacecraft in flight.

The results of the Ka-band experiment will be used to develop models for deep space communications at this frequency and will serve as a learning experience for future operational support. This knowledge will assist both the DSN and flight projects in planning Ka-band communications for missions.

The use of Ka-band is expected to increase data return from future missions by a factor of six. For future missions to take advantage of Ka-band, new spacecraft communications equipment must be de-

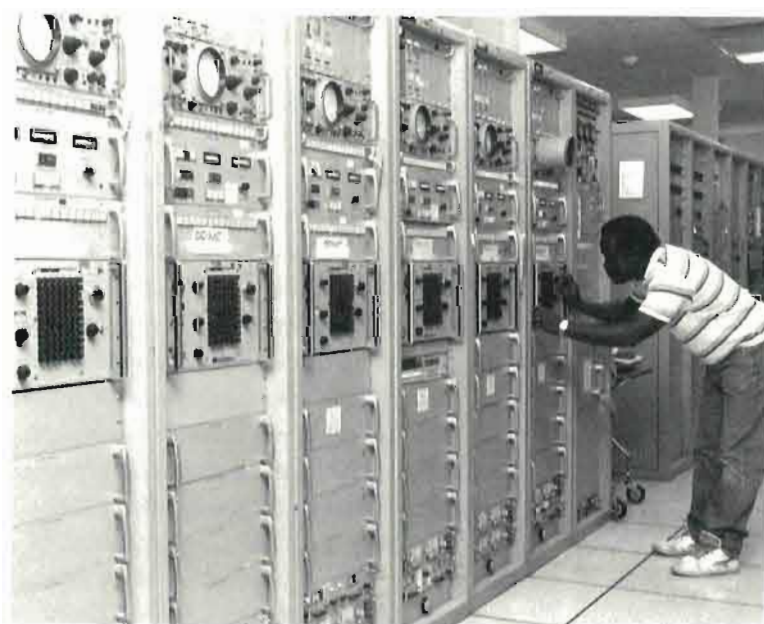
veloped. Two components were demonstrated in 1993 that are compatible with small-spacecraft designs. One is a 0.1-kilogram flat panel antenna that could be integrated into the side of a spacecraft. The second is a solid-state power amplifier with 1.5 watts of radiated Ka-band power. Both components were developed in just under a year employing powerful analytical tools that included visualizing component behavior using supercomputers.

MONITOR AND CONTROL SYSTEM

A new monitor and control system was deployed to operate the Goldstone research and development antenna's diverse state-of-the-art equipment. In addition to enabling the support of several Goldstone radar observations as well as the Ka-Band Link Experiment involving the Mars Ob-

server spacecraft, the new system demonstrated the feasibility of using standard commercial products to meet the DSN's future needs.

The system uses the International Standard Organization's Open System Interconnection standard for process control, the same standard used in the automation of the United States' most advanced factories. Moreover, it is the first JPL-developed monitor and control system that is fully compliant with the Government Open Systems Interconnection Profile, an emerging Federal standard for information systems. Employing multiple commercial products, JPL was able to develop the system from concept to operation in just over a year. In its first year of use, the system has proven extremely flexible, extensible and cost effective.



*S*pacecraft radio signals captured by the Deep Space Network's antennas are converted to useful information by receivers and demodulators like these at the Goldstone complex.

NEW NAVIGATION TECHNIQUES

JPL has developed new processing techniques that can enhance spacecraft navigational accuracy by factors of two to seven. Employing the DSN's standard Doppler radio-metric data system, these techniques use the capabilities of modern computer workstations to model time-varying non-gravitational effects — such as atmospheric perturbations, solar radiation pressure on the spacecraft and small changes in Earth's orientation. Demonstrated this year in collaboration with the Mars Observer and Galileo missions, the new navigation techniques have shown a three-fold improvement in accuracy over conventional approaches for Galileo interplanetary orbit determination. The use of the new techniques will reduce the need for tracking future spacecraft and will allow flight projects — such as the Mars Environmental Survey (MESUR) Pathfinder mission to Mars — to perform high-accuracy interplanetary navigation with reduced spacecraft hardware requirements.

LINEAR ION TRAP

Radio science for future deep space missions has placed stringent requirements on the DSN's frequency standards — the ultrastable clocks that synchronize the network. These requirements will be met by JPL's new linear ion trap (LIT) standard, which suspends a cloud of millions of mercury ions between four charged rods in a

high vacuum. The LIT's stability is better than a billionth of a second per day — more than a factor of three better than the DSN's current clocks. Moreover, the standard is inherently small and reliable, with increased immunity to environmental disturbances.

The first steps toward an operational LIT have been taken with the construction of a pair of prototypes. A third LIT standard is being built for the U.S. Naval Observatory in Washington, D.C., where it will become part of the nation's primary time-keeping capability.

FREE-SPACE LASER COMMUNICATIONS

Laser communications offer potential volume and mass savings for future deep space missions. Semiconductor lasers are being developed to provide the high levels of peak and average power that will be required. At the same time, these lasers have high efficiencies, reducing the demands on spacecraft power.

This year, a laser consisting of a neodymium-doped, yttrium aluminum garnet crystal was developed. This laser has an average output power of 11.5 watts at its natural lasing wavelength of 1.064 micrometers and 3.5 watts when frequency-doubled to green light. The green wavelength power is sufficient for laser communications applications for missions to the farthest reaches of our solar system.

A shift in focus defined 1993 goals

In response to NASA's increasing emphasis on applying advanced technologies to space missions, JPL moved away from long-range, fundamental research and toward specific, targeted developments designed to meet mission requirements. Areas such as micro-component development became increasingly prominent, while fields such as optical systems entered a replanning mode.

During 1993, the Laboratory's advanced technology program successfully transferred to flight hardware builders and other operational users several JPL-developed technologies, including large-scale, ultralight solar arrays, a fiber-optic rotation sensor and a supervisory telerobotics system architecture.

The program also responded to a national technology-commercialization initiative by introducing or expanding mechanisms for industrial collaboration in microelectronics, computers and robotics.

This year, JPL initiated a coordinated microspacecraft program to expand the small-spacecraft development work already under way.

The program evaluated and demonstrated prototype technologies that could lead to significant decreases in spacecraft mass and power usage.

Other development work in 1993 included a terrain-data-processing system that could be used for rover exploration of Mars, and a mobile satellite communications testbed for advanced applications.



*H*igh-speed, solid-state components for space communications systems are developed at JPL's state-of-the-art Microdevices Laboratory.

CENTER FOR SPACE MICROELECTRONICS TECHNOLOGY

The Center for Space Microelectronics Technology focuses primarily on sensors for those portions of the electromagnetic spectrum that are not accessible from Earth because of atmospheric opacity; micro-instruments and microelectronic systems for miniature spacecraft, and high-performance ground computing for mission data analysis and visualization.

A major new activity of the Center is in the area of technology transfer and commercialization. With the goal of boosting the nation's industrial competitiveness, the Center has entered into cooperative agreements with several U.S. companies to develop dual-use technologies that have both Government and commercial applications. These companies represent the automotive, computer, semiconductor, photography, health care and aerospace industries.

In a new industrial partnership, JPL and Caltech Campus were selected by Cray Research, Inc., to receive and develop applications for Cray's first massively parallel supercomputer.

SEMICONDUCTOR LASERS AND PHOTONIC DEVICES

JPL is actively developing semiconductor diode lasers and photonic devices for applications in laser spectroscopy, miniature instruments and communications. Semiconductor materials required for this effort are provided by a new state-of-the-art metallorganic chemical vapor deposition reactor.

This year, highly efficient, high-powered, indium phosphide-based semiconductor lasers were fabricated and delivered for system tests to perform in situ gas phase monitoring of carbon dioxide. JPL's Microdevices Laboratory is currently the only source of diode lasers operating at 1.43 and 2.1 micrometers for measurements of carbon dioxide and nitrous oxide, respectively. An important goal of this

effort is to provide semiconductor lasers at specific wavelengths for the development of an advanced laser spectrometer. The spectrometer will measure gases in the atmospheres of Earth and Mars while still meeting the significantly reduced mass, size and power requirements of future spacecraft.

SUBMILLIMETER-WAVE HETERODYNE RECEIVERS

JPL is NASA's lead center for the development of submillimeter-wave heterodyne receiver technology. Extremely sensitive receivers are required for astrophysical and Earth atmospheric observations of molecular line emissions. These observations will be conducted by future space missions such as the Submillimeter International Mission for astrophysics and the Earth Observing System's Microwave Limb Sounder for atmospheric ozone research.

During 1993, significant advances were made in the development of submillimeter-wave heterodyne receivers — in terms of both sensitivity and frequency. Excellent receiver performance has been demonstrated up to 635 gigahertz, which is over 90 percent of the effective upper-frequency limit for niobium heterodyne detectors. These results exceed the requirements for astrophysics missions by 20 percent. An operational 600–635-gigahertz receiver is currently being used at the Caltech Submillimeter Observatory on Mauna Kea, Hawaii, in an attempt to detect hydrogen chloride in the atmosphere of Venus.

In addition, work began on a new type of superconducting heterodyne detector that uses a hot-electron bolometric effect — that is, thermal response — in a sub-micrometer niobium film. This new device is expected to significantly extend the accessible submillimeter-wavelength range. This effort, as well as work on new designs for integrated niobium nitride circuits, should lead to the development of heterodyne detectors operating at 1200 gigahertz.

SPACE AUTOMATION AND ROBOTICS

JPL serves as lead center for NASA's Rover and Telerobotics Program, which includes research by universities, industry and NASA centers. The program provides the technology to enable new tasks in space science and exploration, inspection, servicing and repair through the development and deployment of innovative telerobotic system technologies. In 1993, a number of JPL-developed technologies began the transition toward operational use — with future applications in Mars exploration, transport-aircraft surface inspections and space station equipment inspections. For example, the Satellite Test Assistant Robot — in more than 50 hours of testing in JPL's 3-meter, high-vacuum, cold-wall, environmental test chamber — has demonstrated its utility for testing prototype Cassini spacecraft hardware.

MICROROVER

In July 1997, as part of a technology experiment, the Mars Environmental Survey (MESUR) Pathfinder project will deliver a microrover to Mars for surface exploration and to evaluate the performance of this type of vehicle on Martian terrain. The current vehicle design is based on several years of research work that culminated in a demonstration of the Rocky 4.0 planetary microrover in June 1992. 1993 efforts focused on translating this design into a flight system, resulting in the successful completion of system requirement and NASA cost reviews.

Rocky 4.3, the current microrover engineering model, uses the chassis and basic control architecture of Rocky 4.0, but applies a new approach to onboard navigation — using laser-light stripers and charge-coupled-device cameras to detect hazards. The current design also incorporates a new computer architecture. To reduce development costs, Rocky 4.3 uses a mix of commercial and flight-qualified parts.

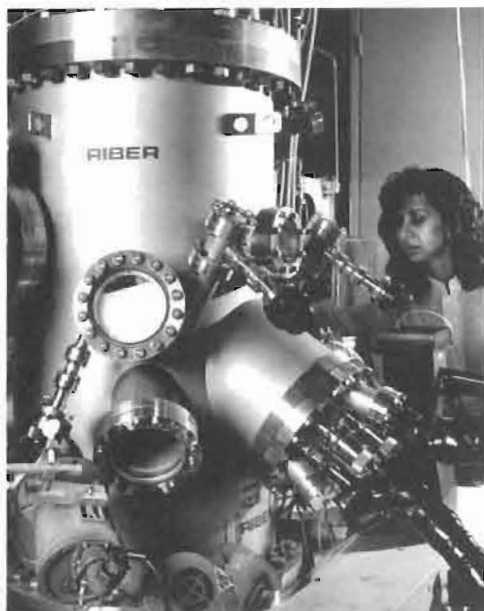
AUTOMATED REMOTE SURFACE INSPECTION

This year saw the completion and successful testing of an automated, telerobotic scanning system with machine-vision flaw detection intended for remote inspection on Earth-orbiting space platforms. The system incorporates a real-time machine-vision capability to examine images (taken from a moving base) for flaw damage and signals the operator upon detection of potential flaws. The methodology is based on subtraction of a "before" reference image from an "after" inspection image, each suitably compensated to account for variations in ambient lighting and misregistration due to sensor position changes.

GENERIC TELEROBOTICS ARCHITECTURE FOR INDUSTRY

The JPL Supervisory Telerobotics Laboratory has a unique local-remote telerobot control capability allowing ground-based operators to safely control robotic systems in the presence of several seconds time delay. The system is easily reconfigurable for changing tasks and continuously monitors and protects the robot — and the component being worked on — from any potential run-away conditions.

The U.S. Air Force's San Antonio Air Logistics Center selected the JPL local-remote telerobot control architecture as a means of improving efficiency and safety within its depot-level maintenance facilities for aircraft such as the C-5A. JPL performed the high-level design of the Air Force's generic telerobot control architecture as the first step in transferring the NASA technology to both the Department of Defense and industry partners who will ultimately develop the commercial version of the JPL design. The use of multiple software modules in the design will allow the private sector to offer the Air Force a reasonably priced initial control system, which can subsequently be upgraded.



ADVANCED SMALL SPACECRAFT TECHNOLOGY

Advanced miniaturized spacecraft and instrument technologies are expected to have broad application to many space science missions, particularly those of strategic interest to the Laboratory. Collectively, these advanced technologies will enable the construction of complete scientific spacecraft, each with a mass under 100 kilograms. Projection of existing technology trends suggests that highly capable 10-kilogram spacecraft may be feasible, perhaps as early as a decade from now. This year, JPL initiated a coordinated Microspacecraft Development Program that will expand the advanced NASA small-spacecraft development work already under way at JPL.

1993 saw significant achievements toward downsizing a number of spacecraft components. In addition, several of the more mature spacecraft technologies began the transition toward qualification and acceptance for operational use, including the Fiber-Optic Rotation Sensor, an optoelectronic replacement for mechanical gyros. A joint development effort between JPL and the Charles Stark Draper Laboratory produced and began testing an engineering

Using molecu-

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JPL can tailor the

properties of semi-

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for specific applica-

tions. In 1993, JPL

applied this tech-

nique to enhance

the response of a

commercial charge-

coupled device for

detection in the ul-

traviolet waveband.

model of the sensor based on spaceflight-quality components. Another example is the lightweight solar array technology developed over a six-year period by JPL and TRW, which has been accepted into the baseline design for one of NASA's Earth Observing System satellites.

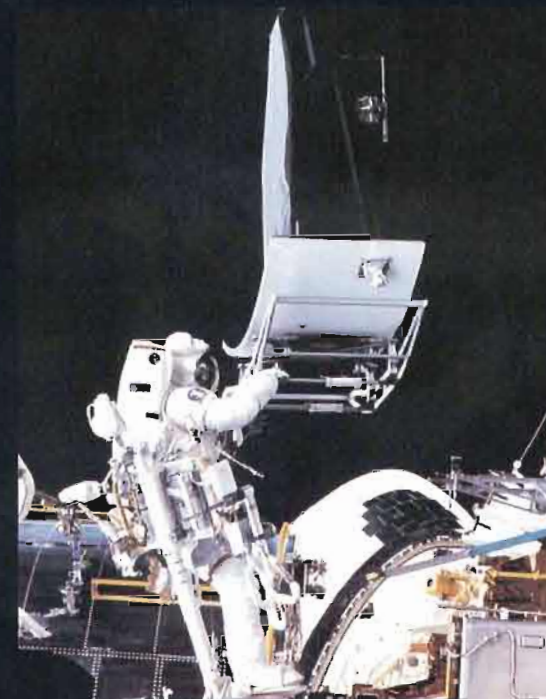
MICROSPACECRAFT TECHNOLOGY

This year, the Microspacecraft Development Program evaluated and demonstrated prototype microspacecraft technologies that could lead to order-of-magnitude decreases in subsystem masses and power usage. Included in these activities were 100-gram miniature gyros, a 300-gram miniature star camera and a complete spacecraft command and data-handling subsystem having a mass of only 2 kilograms and using just 2 watts of power. These technologies were recently developed by industry for NASA and other Government agencies.

In addition, JPL contracted with Utah State University's Space Dynamics Laboratory to construct two 5-kilogram prototype microspacecraft structure subsystems fabricated with aluminum isogrid technology. Known for having low mass and high stiffness, isogrid technology may lead to re-

Breakthroughs in Seeing

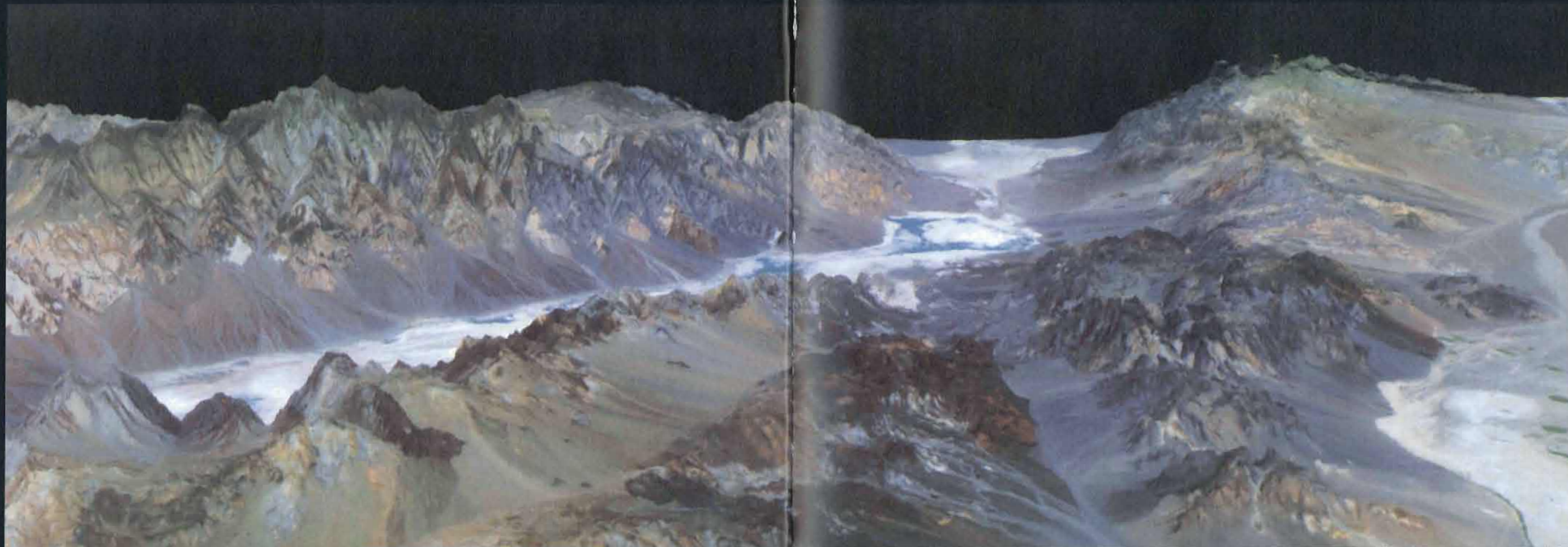
The Laboratory logged significant achievements in 1993. This color insert provides highlights from the year: the replacement of the Wide Field/Planetary Camera with a new camera that restores the Hubble Space Telescope's ability to see stars and galaxies with unmatched clarity, the use of supercomputers to visualize complex data and the global monitoring of Earth's atmosphere.



The Wide Field/Planetary Camera 2 was installed in the Earth-orbiting Hubble Space Telescope in December 1993. The new camera corrects for the flaw in the telescope's main mirror.

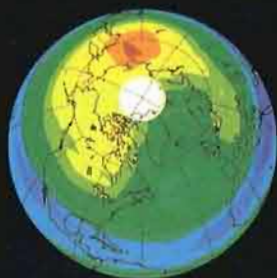
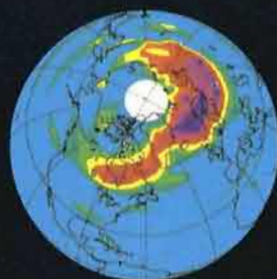
Images from the new camera reveal that the dense star cluster R136 is composed of more than 3,000 stars. The brightnesses and colors of these stars can be measured accurately.



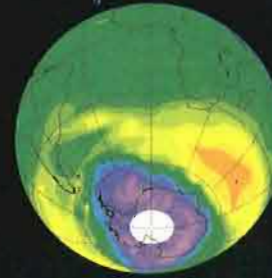
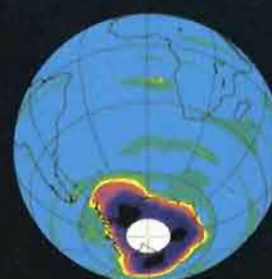


February 1993

Data from the Microwave Limb Sounder on NASA's Upper Atmosphere Research Satellite were used to create these four maps of Earth, which show atmospheric ozone and chlorine monoxide levels.



September 1993

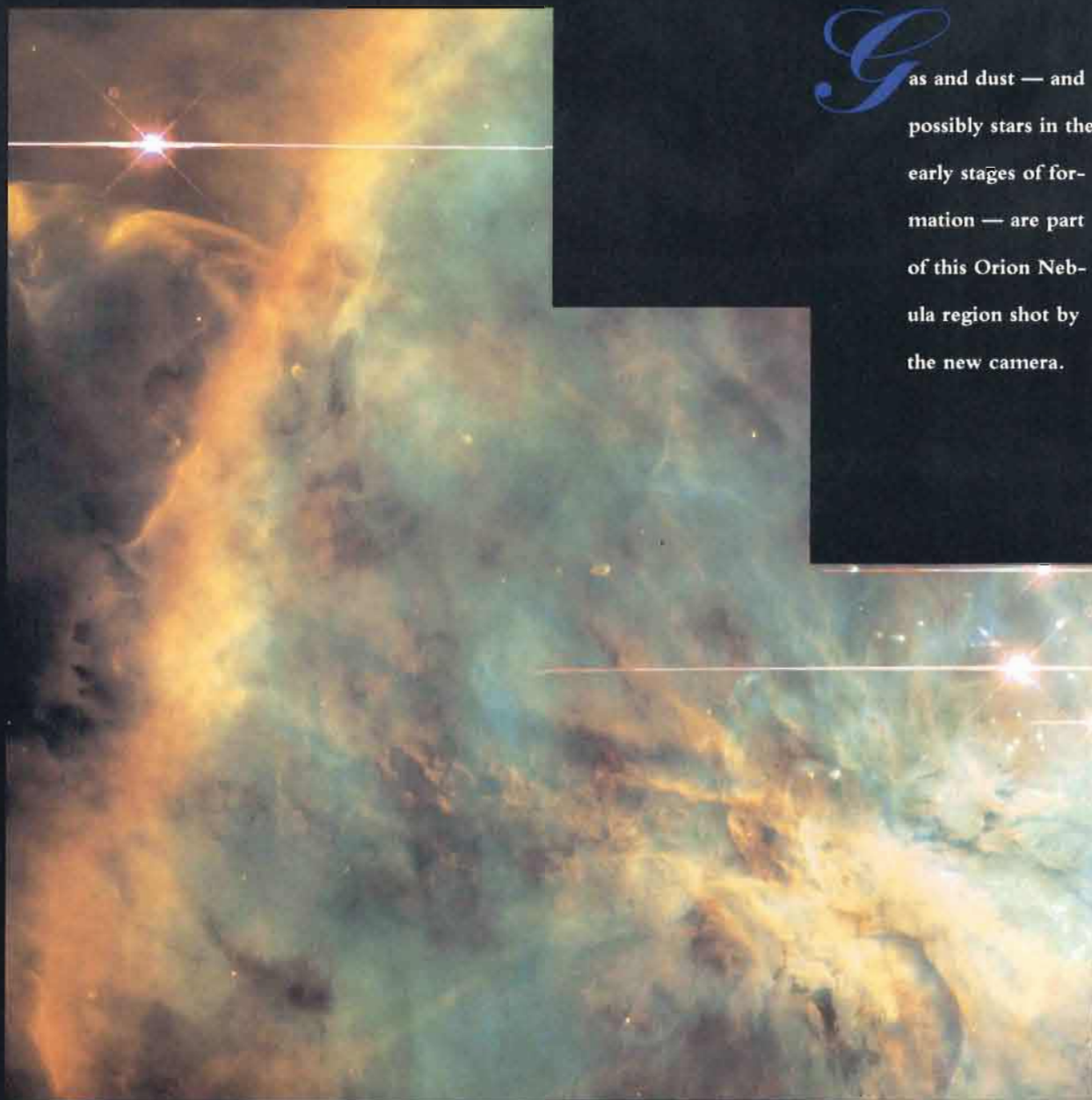


California and Nevada's Death Valley is simulated in this three-dimensional picture generated on the Caltech Campus-JPL CRAY T3D supercomputer. The image suggests the view from a plane flying over the valley.

*E*ta Carinae, an exploding star captured by the Wide Field/Planetary Camera 2, is about 10,000 light years from Earth.



*G*as and dust — and possibly stars in the early stages of formation — are part of this Orion Nebula region shot by the new camera.



duced manufacturing costs and more flexibility in the spacecraft integration process.

During 1994, these microspacecraft technology evaluation efforts will be collocated in JPL's Flight System Testbed, where the various components will be integrated and evaluated at the system level to investigate innovative microspacecraft architectures.

COMPACT HIGH-EFFICIENCY POWER SUPPLIES

High-efficiency synchronous rectification circuitry has been developed to reduce losses in spacecraft power converters by 50 percent. Low-loss synchronous rectification can improve the 5-volt-direct-current conversion efficiency of existing technology by more than 10 percent. This technology has been incorporated into several power converters on the Cassini spacecraft. Hybrid fabrication of these converters (including both large-scale integrated circuits and individual components) will provide a volume reduction of 80 percent and a mass savings of 40 percent as compared with earlier Cassini fabrication efforts.

RECHARGEABLE LITHIUM BATTERIES

JPL has been developing rechargeable lithium batteries that have a high specific energy — that is, a high energy output per unit mass — for NASA planetary and other missions. These batteries can provide three to four times the weight and volume savings over existing batteries for space applications, such as nickel cadmium. Three types of batteries under development employ, respectively, lithium titanium disulfide, lithium ion and solid-state lithium-polymer electrolytes.

As of late 1993, the lithium titanium disulfide batteries had achieved significant performance: 1,000 charge-discharge cycles and 125 watt-hours per kilogram when operated at 50-percent depth of discharge and at ambient temperature. The lithium ion battery, being developed for

high- and low-Earth-orbit missions requiring long cycle life, utilizes a carbonaceous anode material to replace the lithium foil. In a major advance in the development of this type of battery, JPL has identified a low-cost, commercially available, rechargeable material with high specific capacity (ability to hold charge) together with a compatible electrolyte.

The development of the lithium-polymer electrolyte battery has centered on identifying a solid polymer that has adequate conductivity and stability. Materials have now been prepared and characterized, and small experimental cells have been fabricated. Cells with gel polymer and other polymer electrolyte have achieved more than 40 charge-discharge cycles in the laboratory. These cells have been projected to achieve greater than 150 watt-hours per kilogram and would be simple to manufacture and handle.

ADVANCED OPTICAL SYSTEMS TECHNOLOGY

Telescopes rely on aperture size for both light-gathering power and spatial resolution. If a telescope is too small, it cannot reach its scientific objectives. However, the trend in future space missions is toward smaller launchers and spacecraft. To adapt to this changing environment and still achieve basic scientific goals, JPL's optical system technology program has initiated work in technologies that could lead to deployable telescopes. These telescopes would unfold from containers that could be carried by small spacecraft. Once the telescopes were deployed, precision alignment would be achieved by active control of the optical surfaces. Much of 1993 was spent reorienting JPL's program from developments for large space observatories to designing for deployable precision optical systems.

The optical systems technology program continues to support nearer term requirements for optical design software,

cryogenic mirror technology, specialized submillimeter mirror materials and components for stellar interferometers.

ADVANCED COMMUNICATIONS TECHNOLOGY

MOBILE SATELLITE COMMUNICATIONS

Recognized as a leader in mobile satellite communications technology, JPL is preparing to field an experimental mobile satellite communications testbed to operate with NASA's Advanced Communications Technology Satellite (ACTS). This system will operate at K- and Ka-bands to evaluate the use of these frequencies for all types of mobile communications applications — from land to aeronautical. This effort is part of a larger ACTS program that is expected to pave the way for the next generation of communications satellite technology and services. The testbed, which will demonstrate speech, video and data transmissions in the Ka-band mobile satellite communications channel, will be used to characterize the Ka-band channel through a series of propagation experiments.

The experimental period of ACTS operation was initiated in December and will last approximately four years. Industry involvement in the mobile experiments is heavy, ranging from propagation experiments to demonstration of new services such as slow-scan video and direct broadcast audio for standard radio broadcasts.

AERONAUTICAL SATELLITE COMMUNICATIONS

Working closely with its industry partners, JPL in 1993 initiated development of a broadband aeronautical terminal for experimentation with ACTS. This terminal will be utilized to determine the feasibility of high-data-rate aeronautical communications at Ka-band.

The aeronautical communications experiments will demonstrate and charac-

terize the performance of high-data-rate aeronautical Ka-band communications; characterize the propagation effects of the communications channel during take-off, cruise and landing phases of flight, and provide the groundwork for an eventual commercial Ka-band aeronautical satellite communications system.

OTHER TECHNOLOGICAL ADVANCES

VISUAL PROGRAMMING

Visual programming produces software programs by creating and connecting icons instead of using traditional text. The icons represent functions (subroutines) whose connections are represented as "wires" to symbolize paths that variables travel from one function to the next. Visual code is actually the diagram of icons and wires rather than a text file of sequential instructions.

The Measurement Technology Center at JPL has used visual programming to create applications for component or system simulation, prototyping, ground support for flight experiments, remote data acquisition, pure analysis, medical simulation, training and even circuit design — well beyond the original objective of data-acquisition analysis and control.

This approach allows a reduction in software development time and cost by a factor of 4 to 10. It enables configuration of measurement systems — including software and sensors as well as signal conditioning and data display and control capabilities — that is more rapid, less expensive and higher in quality than previously possible. Visual programming has been used to configure systems that support Galileo, Cassini, Voyager, the NASA Scatterometer, the Brilliant Eyes Ten-Kelvin Sorption Cryocooler Experiment (BETSCE), Mars Observer and other flight projects and experiments.

TERRAIN ANALYSIS SERVER

1993 saw successful proof-of-concept demonstrations of the Terrain Analysis Server, a computer system that provides terrain data and terrain-based reasoning tools to analysts at workstations — multi-processor SUN computers — connected by a local area network.

The Server's suite of software tools was designed to work with an interactive map display package developed under the same program, providing graphic visualization of the generated data. The system can generate visible line-of-sight and radio-signal strength overlays, along with full-color and stereo-perspective renderings of maps and images draped over elevation data; another system capability is tactical movement analysis for determining the optimal path across a given geographic area for a variety of vehicles traveling both singly and in groups. With minimal modification, the Server could serve operational needs of a Mars rover exploration mission.

A microrover

based on JPL's

Rocky 4.3 design

(pictured) will explore the surface of Mars in 1997.

Rocky 4.3 uses special cameras and laser-light stripers to detect hazards.



DIRECT-OXIDATION FUEL CELL

JPL has made a significant breakthrough in the conversion of chemical to electrical energy by developing a direct-oxidation fuel cell. This power technology has several significant advantages that make it an ideal candidate for many portable power applications — from personal power packs to electric vehicles. Using a 6-percent solution of methanol and air as fuel, the JPL cell operates at or near room temperature and produces only carbon dioxide and water as byproducts.

Without the need for a complex and bulky fuel reformer or hydrogen storage, this solid-state cell — there is no liquid electrolyte — is contained in a small (5- × 5-centimeter) package with an energy density approaching 1,000 watt-hours per kilogram (about 10 times that of the best advanced batteries). The cell may be scaled and stacked to produce the specific power levels required by various applications.

Rapid developments marked this year

Applications projects at JPL are important technical contributions to the national interest. In 1993, the Laboratory's mix of technical and management skills was applied in work for sponsors such as the Department of Defense, the Department of Transportation and others.

During the year, the U.S. Army completed final acceptance tests for the All Source Analysis System and declared it operational. The system is being deployed at a number of Army sites. Another effort, the command and control center in development for the U.S. European Command, has served as the pattern for several other projects in

terms of both architecture and management approach.

One key to the success of these defense projects has been JPL's rapid development method, in which successive increments of capability are developed and installed, leading to a preliminary system for early use. Successive upgrades then result in a final system that meets all customer requirements. The method is being extended to projects for NASA and other sponsors.

In other activity, JPL delivered experimental payloads to defense satellites and began initial development for intelligent systems to improve U.S. surface transportation.



The anthropomorphic robot hand of this tele-manipulation system will be able to use common tools and other equipment at a remote work site.

ALL SOURCE ANALYSIS SYSTEM

During 1993, JPL completed development, test and delivery of the primary components of the Block I All Source Analysis System (ASAS). Block I ASAS provides the U.S. Army with an initial capability for automated processing, correlating and fusing of intelligence data.

ASAS hardware and software have both successfully completed technical and operational testing by the Army and are currently being fielded to high-priority Army units. During the year, JPL delivered final enhancements to Block I ASAS — the first system of its type ever to be security-accredited for fielding — and began transition of field support and maintenance to the Army.

JPL also began prototype development of an advanced-configuration ASAS using Alpha Reduced Instruction Set Computer (RISC) processors — procured from Digital Equipment Corporation — to dramatically improve the system's performance in terms of speed, power and size. This development has exceeded expectations and will be the basis for an ASAS upgrade in 1994.

JPL's involvement in the project is expected to continue through 1994, to complete the Alpha RISC upgrade and the transferring of ASAS support functions to the Army.

EUCOM COMMAND CENTER

JPL is implementing for the U.S. European Command (EUCOM) a command and control system that processes and integrates information to assist the U.S. EUCOM commander-in-chief and the commander's staff in making decisions regarding military operations in Europe and most of Africa.

Located at the U.S. EUCOM Headquarters near Stuttgart, Germany, the system contains numerous servers and over 60 workstations linked by high-speed local area networks. System features include automated message handling; database man-

agement; map and text manipulation, and briefing and display. The Command — which is responsible for managing humanitarian relief efforts, treaty monitoring, military activities and European troop reduction operations — will use the automated system to distribute messages; generate briefings, and prepare, coordinate and release situation reports.

The following characteristics give the system unique utility: generic, open-system architecture adaptable to a changing environment; maximum use of commercial and Government-developed software; user-friendly data management and reporting; centralized system monitor and control; use of inherited technology, and sharing of technology with other projects.

During 1993, JPL delivered several software upgrades to improve the system's user interface and functional capabilities, demonstrated the system at the Pentagon for key military personnel and supported test-bed activities to electronically connect several military data interfaces to the system. JPL was recently selected to participate in a proof-of-concept demonstration of the EUCOM system for application to the new Global Command and Control System sponsored by the Joint Chiefs of Staff.

COMMAND AND CONTROL AUTOMATION

Since October 1989, JPL's Command and Control Automation project has developed, integrated and tested a command and control system for the U.S. Transportation Command at Scott Air Force Base in Illinois. The system allows the U.S. Transportation Command to monitor, coordinate and direct all U.S. peacetime and wartime transportation operations, as well as to maintain the status of assigned transportation forces and assets.

During 1993, numerous enhancements and new functional capabilities were incorporated into the system to improve operations. Perhaps the most important new



feature is connection of the system to the Department of Defense's Automatic Digital Network through the use of the JPL-developed Automated Message Handling System, which has received an unconditional certification for the processing of classified data.

ANALYSIS AND TRAINING SYSTEMS

In previous years, JPL supplied a Corps Battle Simulation (CBS) system to the U.S. Army as a corps- and division-level battle trainer simulating up to 7,000 combat units. In 1993, JPL completed an extension of the system's capabilities to manage up to 20,000 combat units, or 6 corps. The system allows corps, division and brigade commanders and their staffs to exercise wartime duties in simulated battle drills.

In another, earlier development, the U.S. Army, JPL and other organizations successfully linked CBS with the U.S. Air Force's training simulation system. In 1993, JPL and the Army's Combined Arms Support Command demonstrated a

The Laboratory

has developed a telerobotic system that could perform remote surface inspections on space platforms, protecting astronauts from unnecessary risks.

preliminary linkage between CBS and the Combat Service Support Training Simulation System. Plans now call for linking CBS with additional military training systems in 1994 and beyond.

During 1993, JPL significantly upgraded the CBS terrain-representation capability, thereby eliminating former limitations on combat and detection and providing greater realism for units being trained. JPL also developed and applied artificial-intelligence techniques that reduced the number of operators required for training exercises.

COMMAND AND CONTROL SUPPORT AGENCY

The Laboratory is modernizing and automating a large, complex command and control center system for the U.S. Army Command and Control Support Agency in the Pentagon. The system — which provides 24-hour-a-day support to the agency's critical missions — is part of a facility that continuously monitors worldwide political, military and economic events and tracks and responds to national emergencies.

Begun in May 1991, the JPL project uses a rapid research and development approach — developed on previous JPL projects — in which the required system capabilities are prioritized and the hardware and software upgrades are provided via incremental deliveries at approximately 9–12-month intervals. This approach quickly makes available desired new capabilities to the 300 system users to support daily peacetime activities and activities during crises.

The project has completed three deliveries and is starting work on the fourth. With completion of the third incremental delivery in October 1993, the system achieved “initial operational capability,” able to support the agency in the areas of office automation, data systems, automated message handling, briefing and display, map graphics, security and connectivity to other secure systems.

ADVANCED COMPUTER SIMULATION

The Advanced Laboratory for Parallel High-Performance Applications specializes in high-performance solutions to information-processing problems through use of parallel and advanced computer network technologies. Sponsored primarily by the U.S. Air Force Electronic Systems Center, the laboratory has focused on air defense, which includes counter-drug applications, and on ballistic missile defense. In both areas of effort, JPL has developed and demonstrated new algorithms for tracking potentially hostile vehicles and has produced and demonstrated graphical user-interface displays that may be used in a future command center.

Computer-driven simulations written by JPL have been used to “fly” the aircraft and missiles and to provide the simulated ground or space detections that are sent to command-center trackers. In 1993, the Laboratory delivered to the Advanced

Research Projects Agency a powerful advanced simulation framework that supports complex discrete-event simulation for the agency’s time-critical target activities.

Related work is focused on providing the human user with a realistic view of visual data. This research, known as “rendering,” transforms two-dimensional data sets into three-dimensional perspective views. This year, the Laboratory developed techniques for rendering extremely large data sets at high speeds. The Caltech Campus’ Intel Touchstone Delta supercomputer — in conjunction with a High-Performance Parallel Interface that carries information at a high rate (millions of bits per second) between the Caltech Campus and JPL — makes possible these massive computations. This capability is directly applicable to interactive exploration of very large databases for NASA science missions.

AUTOMATED SYSTEMS DEVELOPMENT

JPL is assisting the Federal Aviation Administration (FAA) in the development of the Advanced Automation System, which will incorporate modern air traffic controller workstations, computer processors and software capable of handling civil and military air traffic projected beyond the year 2000. JPL is also continuing to assist in overseeing the development of the Voice Switching and Control System, which will provide integrated radio and interphone/intercom services for FAA Air Route Traffic Control Centers.

The Laboratory has provided assistance in such areas as system engineering analysis, design, development and management support for both the Advanced Automation System and the Voice Switching and Control System. In 1993, JPL-support activities for the Advanced Automation System included weather-products evaluation for the air traffic controllers and weather-measurement systems engineering; the

Laboratory also assisted in the management of requirements, external interfaces and functionality and the resolution of system design issues.

In February, JPL delivered the Traffic Simulation Unit — developed by the Laboratory to be used in the performance evaluation of the Voice Switching and Control System — on schedule to the FAA Technical Center after the Unit’s successful completion of FAA acceptance tests.

INTELLIGENT VEHICLES AND HIGHWAYS

After a hiatus of about eight years, JPL has again begun to work in the area of surface transportation — as part of a national effort to increase mobility and safety within the U.S. surface transportation system while also reducing energy use and environmental impact. This national effort has been largely focused through the Intelligent Vehicle-Highway Systems program, which will apply information, sensing, computing, control and other advanced technologies — areas of JPL expertise — to improve the surface transportation system.

In December 1992, JPL was selected by the Federal Highway Administration to develop the architecture of the Intelligent Vehicle-Highway Systems. This architecture will form the framework for future development to ensure that system elements are compatible nationwide. The development process got under way in 1993 with the selection of four contractors to develop candidate architectures, of which one will be selected for further development.

SPACE TECHNOLOGY RESEARCH VEHICLE

In October 1993, JPL delivered a small, sophisticated payload package to the British Ministry of Defense for integration into the Space Technology Research

Vehicle satellite, which is scheduled for a May 1994 launch. The development of the payload package — sponsored by the Ballistic Missile Defense Organization — was accomplished rapidly and within severe weight, power and volume limitations.

The payload package includes four experiments, which are designed to demonstrate technology that could find wide application on a variety of scientific and military satellites. One experiment will evaluate techniques for the suppression of vibrations induced by the operation of a Stirling Cycle cryocooler. Suppression of cryocooler-induced vibrations is a critical requirement for applications requiring highly accurate pointing of imaging surfaces, such as infrared detector arrays, which must be operated at cryogenic temperatures. The vibration-reduction experiment will evaluate the performance of two different suppression schemes.

The other three experiments take advantage of the opportunity presented by the satellite’s geosynchronous transfer orbit — which passes through the Van Allen radiation belts in the transition from a low to high Earth orbit — to evaluate the sensitivity of new component technologies to space radiation. These experiments include the use of a static random-access memory (SRAM) device as a radiation dosimeter/mass analyzer, the determination of the radiation sensitivity of a new type of infrared detector and the evaluation of neural-network performance in the presence of radiation-induced upsets.

RADIATION AND RELIABILITY ASSURANCE EXPERIMENT

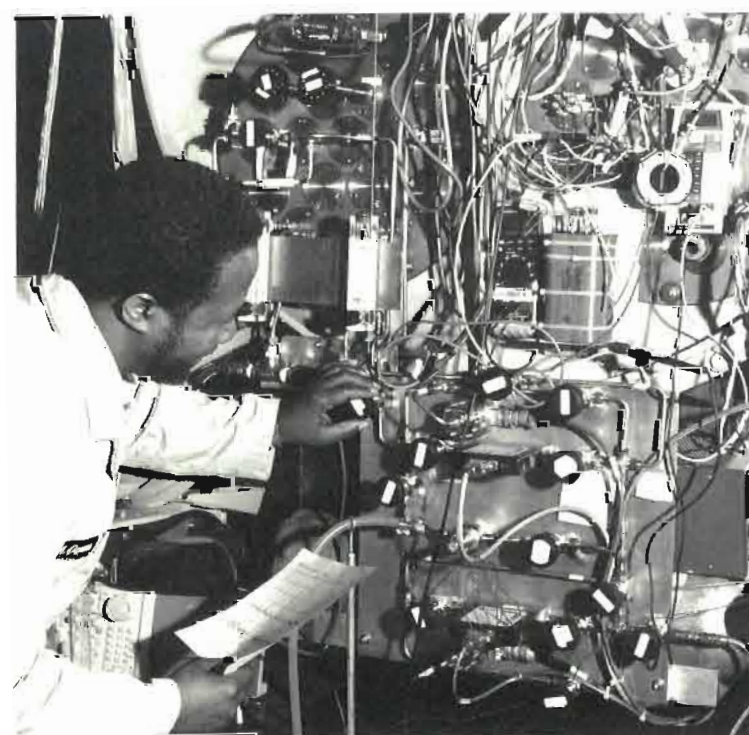
The Department of Defense and NASA began a cooperative program in 1992 to test advanced lightweight technologies for the Ballistic Missile Defense Organization by flying them in a radiation-stressed environment. As part of this program, the

Clementine spacecraft and its upper propulsion stage — which will also function as a satellite — will each carry a complement of environmental sensors designed to verify the effects of the space environment on advanced electronic components and sensors under test for the Ballistic Missile Defense Organization.

The spacecraft and satellite are being designed and will be built and launched in less than two years, for a flight mission lasting less than nine months. They are scheduled to be launched into a high-inclination orbit from Vandenberg Air Force Base in California on a Titan IIG launch vehicle in January 1994. After a series of orbital adjustments, the spacecraft will be placed into lunar orbit for two months, then embark on a trajectory that will take it within 100 kilometers of the near-Earth asteroid Geographos in August 1994. The satellite will remain in Earth orbit, where it will conduct environmental-effects experiments.

In 1993, JPL developed two identical device packages — one for the spacecraft and one for the satellite — as part of the Radiation and Reliability Assurance Experiment (RRELAX) and delivered them to the Clementine mission. Each package contains a linear charge-coupled-device experiment, integrated circuits to monitor radiation and a digital radiation-test chip to evaluate radiation effects on two families of complementary metal oxide semiconductor (CMOS) devices. In total, 166 devices (including those that will monitor radiation) will be tested for their sensitivity to the radiation environment. The two RRELAX device packages were designed, constructed and flight qualified in about six months.

RRELAX data will aid system designers in optimizing fault-tolerant space systems and allow the evaluation of techniques for extrapolating laboratory data to a space environment. Ultimately, the information will contribute to space systems and sensor designs that are less sensitive to radiation.



A Russian-made thruster, to be used for stabilizing the orbits of communications satellites, undergoes performance and lifetime testing at the Laboratory.

SPACE NUCLEAR POWER

A rapid-development approach was initiated by the Space Nuclear Power-100 project in 1992 with the goals of making available technology for near-term planetary missions using nuclear electric propulsion, and of providing improved technology for later missions. The near-term technology development was completed late in 1992, except for the thermal-to-electric energy converter, the reactor control drive actuator and the pump for circulating liquid-metal reactor coolant.

During 1993, the emphasis was on completing the development of this hardware. The first converter was fabricated in September. Testing of a control drive actuator

subassembly began at the end of September. The critical bonding steps for assembling the thermoelectric cells and the pump ducts were completed by the end of September, and the pump assembly was completed in December. Testing during fiscal year 1994 will validate these component technologies for future applications.

The project is scheduled to be terminated at the end of fiscal year 1994, along with a number of other developments in the area of space nuclear power. However, technology developed by the Space Nuclear Power-100 project is well documented and will be available to meet future requirements for space reactor power systems.

JPL responds to the country's needs

mission-oriented, "hands-on" organization, the Laboratory carries out space science, engineering and applications projects of significance to the nation and assists industry in developing advanced technology for commercial use. As employees of Caltech, JPL personnel continue to strive for the highest standards of achievement and excellence, applying the principles of Total Quality Management to meet customer quality requirements, budgets and schedules.

Research and development costs for the fiscal year 1993 ending in September were \$1.072 billion, a 3-percent decrease from 1992. Costs for NASA-funded activities declined

0.7 percent to \$855.5 million; costs for non-NASA activities declined 10.9 percent to \$216 million.

The Laboratory's work force decreased by year-end to 6,160, compared to 6,430 in 1992 and 6,359 in 1991. JPL's procurement obligations during the fiscal year totaled \$502 million, 26.5 percent less than in 1992. Of these outlays, \$439 million went to business firms, including \$154 million to small businesses; \$35 million to small disadvantaged businesses; \$22 million to women-owned businesses, and \$2.4 million to historically Black colleges and universities and other minority educational institutions.



*S*pace instruments that can operate across the electromagnetic spectrum are created in JPL's new Observational Instruments Laboratory.

HONORS AND AWARDS

A number of special honors, NASA Honor Awards and Laboratory honors were presented to JPL employees in recognition of their exceptional achievements and service. Special honors are awarded to

Special Honors

AVIATION WEEK AND SPACE TECHNOLOGY LAURELS 1993

Magellan spacecraft team:
Saterios S. Dallas, Daniel T. Lyons, Anthony J. Spear and Douglas G. Griffith (JPL); Durwin Schmitt and Bill Willcockson (Martin Marietta), for pioneering the aerobraking technique and gathering new Venus gravimetry and radar data

TOPEX/POSEIDON project:
Charles A. Yamarone, Jr., and Lee-Lueng Fu (JPL); Linwood Jones and William C. Patzert (NASA); Michel Dorrer and Michel Lefebvre (Centre National d'Études Spatiales), and the Fairchild Space team, for substantially advancing our understanding of the world's oceans and their role in the global environment

CORPORATE INNOVATION RECOGNITION AWARD, INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS

Jet Propulsion Laboratory, for contributions to electrical, electronic and computer engineering related to the automated exploration of space

CORRESPONDING MEMBER, INTERNATIONAL ACADEMY OF ASTRONOMY

Arvydas J. Kliore

ELECTED FELLOW, AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

Ben K. Wada

ELECTED FELLOW, AMERICAN METEOROLOGICAL SOCIETY

David Halpern

both individuals and groups by a variety of organizations and professional societies. The annual NASA Honor Awards are presented to JPL employees by NASA in recognition of outstanding individual achievements.

ELECTED FELLOW, AMERICAN PHYSICAL SOCIETY

Paulett C. Liewer

FRANÇOIS-XAVIER BAGNOUD AEROSPACE PRIZE, INAUGURAL

William H. Pickering (retired), for extending our understanding of Earth and our planetary system

INTERNATIONAL HISTORIC MECHANICAL ENGINEERING LANDMARK, AMERICAN SOCIETY OF MECHANICAL ENGINEERS

Voyager 1 and Voyager 2 spacecraft

LEW ALLEN AWARDS FOR EXCELLENCE

- Pierre F. Baldi
- Usama M. Fayyad
- Seth R. Marder
- Padhraic J. Smyth

PRESIDENT-ELECT, AMERICAN GEOPHYSICAL UNION

Marcia M. Neugebauer

PRIX D'ASTRONAUTIQUE 1992

TOPEX/POSEIDON project:
Charles A. Yamarone, Jr. (JPL), and William C. Patzert (NASA)

RESEARCH AND DEVELOPMENT 100 AWARD

Thomas W. Kenny, William J. Kaiser, Judith A. Podosek, Erika C. Vote and Joseph K. Reynolds, for the Uncooled Infrared Tunnel Sensor

TECHNOLOGIST OF THE YEAR, NATIONAL TECHNICAL ASSOCIATION

James King, Jr.

NASA Honor Awards

OUTSTANDING LEADERSHIP MEDAL

- Duane F. Dipprey
- David D. Evans
- Marcia M. Neugebauer
- Charles A. Yamarone, Jr.

EXCEPTIONAL ACHIEVEMENT MEDAL

- Nellis C. Adams
- Rajiv S. Desai
- Tom W. Hamilton
- Michael J. Klein
- Phyllis J. Lopeman
- George D. Pace
- Reuben M. Ruiz
- Alfred R. Zieger

EXCEPTIONAL ENGINEERING ACHIEVEMENT MEDAL

- Paul G. Backes
- Edward T. Chow

EXCEPTIONAL SCIENTIFIC ACHIEVEMENT MEDAL

- Henry G. LeDuc
- Aden B. Meinel
- Joe W. Waters

EXCEPTIONAL SERVICE MEDAL

- Jerome E. Abraham
- Philip C. Allin
- Kenneth L. Atkins
- William E. Badman
- Douglas W. Beasley
- Joseph G. Beerer
- Joseph W. Bott
- Allen P. Bowman
- G. Curtis Clevin
- Nickolas S. Climes
- Jean W. Clough
- Lynne P. Cooper
- James R. Curtis
- E. S. "Ab" Davis
- Samuel G. Deese
- Michael R. Diethelm
- Henry M. Doupe
- Fraser W. Draper

- Roger G. Gibbs
- Marthella W. Greene
- Richard A. Grippi, Jr.
- Carole L. Hamilton
- Daniel J. Hoppe
- James H. Kelley
- Robert C. Kinkade
- Robert F. Klotz
- Anne-Marie Krause
- Michael C. Lou
- William B. Mabe
- Warren L. Martin
- Jitendra S. Mehta
- Marjorie P. Meinel
- David P. Miller
- Timothy N. Munson
- Susan C. Murphy
- Timothy P. O'Donnell
- Steven C. Ogle
- Floyd G. Olson
- John C. Peterson
- Dusan Petrac
- Dennis L. Potts
- Robert V. Powell
- Pamela H. Ray
- Eugene C. Reiz
- Gail K. Robinson
- Ralph B. Roncoli
- James R. Rose
- Sheldon N. Rosell
- Albert C. Rush
- Terry D. Scharton
- Ted J. Sivalon
- William J. Sleigh
- Fred S. Soltis
- Thomas W. Starbird
- Donald J. Starkey
- Ellen R. Stefan
- Joseph A. Wackley
- Charles R. Weisbin
- Richard M. Welby
- Linda L. Welz
- Helmut C. Wilck
- Alvin M. Willems
- Ronald Y. Yoshida
- Michael P. Zydowicz

SPECIAL APPOINTMENTS**DISTINGUISHED VISITING SCIENTIST**

The Distinguished Visiting Scientist Program promotes interchange among researchers worldwide and Caltech Campus and JPL scientists and engineers. The program aims to advance areas of research of particular interest to JPL by providing a forum for the exchange of ideas, research methods and technical expertise. The following individuals were appointed to the Distinguished Visiting Scientist position in 1993 and have spent from 2 to 12 months at JPL:

- Charles A. Barth, *Astrophysical, Planetary and Atmospheric Science* — University of Colorado, Boulder, Colorado
- Junichi Nakamura, *Advanced Imager Technology* — Olympus Technology Development Center, Torrance, California
- Roald Sagdeev, *International Space Policy* — University of Maryland, College Park, Maryland
- Donald E. Shemansky, *Aerospace Engineering* — University of Southern California, Los Angeles, California

SENIOR RESEARCH SCIENTIST

The position of Senior Research Scientist is awarded to scientists who have shown outstanding leadership and achievements in their fields. Researchers will retain this appointment for as long as they are employed in a research capacity at JPL. Four individuals received this honor in 1993:

- Jay H. Lieske, *Dynamical Astronomy*
- W. Timothy Liu, *Physical Oceanography/Air-Sea Interaction*
- Michail Zak, *Nonlinear Dynamics*
- Richard W. Zurek, *Atmospheric Dynamics*

SENIOR TECHNICAL SPECIALIST

The position of Senior Technical Specialist is awarded by JPL to scientists or engineers who through their careers have made exceptional contributions to the Laboratory in terms of leadership and achievement in their fields. The following individuals received this appointment in 1993:

- George A. Frascchetti
- William J. Hurd
- Krishna M. Koliwad
- Charles E. Lifer
- Frank D. Palluconi
- John A. Scott-Monck
- John P. Slonski, Jr.
- Richard L. Stoller
- Richard J. Terile
- Raymond J. Wall
- Neil J. Yarnell
- Thomas P. Yunck

PATENTS AND NEW TECHNOLOGY

During 1993, the JPL Office of Patents and New Technology submitted to NASA reports on 247 inventions or technical innovations resulting from JPL work. The U.S. Patent and Trademark Office issued 44 patents to Caltech and NASA for inventions developed at the Laboratory. NASA approved and JPL conferred on JPL employees monetary awards totaling \$175,800, which included approximately \$75,000 in NASA Tech Briefs-related awards and also the following:

- Marvin Perlman, \$15,000 (lifetime achievement award), for outstanding contributions related to cryptography and to algebraic error-correction encoders and decoders for space telecommunications
- Robert F. Rice, \$15,000, for the origination and innovative applications of the Rice Algorithms for lossless digital data compression

- Slobodan Cuk, \$1,000, for the push-pull switching power amplifier
- J. Brooks Thomas, Jr., \$1,000, for a highly digital front end for Global Positioning System receivers

In addition to the individuals listed above, several hundred JPL inventors or innovators received monetary awards totaling \$143,800.

DISCRETIONARY FUNDING

The Laboratory encourages work on innovative and seed research efforts — even those that have not received conventional task-order funding. To enable such efforts, JPL provides two important sources of discretionary financial support: the Director's Discretionary Fund and the Caltech President's Fund.

DIRECTOR'S DISCRETIONARY FUND

The Director's Discretionary Fund is the major resource for innovative and seed efforts that do not receive task-order funding. Proposals eligible for Fund monies cover a broad range of sciences and technologies. Areas of recent emphasis have included automation and robotics; advanced optical systems, and microinstruments and small payloads.

In 1993, NASA contributed \$3.5 million to the Fund; various reimbursable funds contributed an additional \$234,000. During the year, the Fund initiated 30 new research tasks; awarded additional funds to extend the objectives of 5 ongoing tasks, and provided assistance to several other support efforts.

Recognizing the mutual benefit, the Director's Discretionary Fund specifically encourages collaboration between JPL staff members and faculty and students at the Caltech Campus and other academic institutions. Eleven of the new or extended principal tasks funded in 1993 involved 14 university faculty collaborators.

CALTECH PRESIDENT'S FUND

The Caltech President's Fund provides a second source of discretionary funding. Currently at a level of \$1 million per year, the Fund is sponsored by Caltech and NASA on a dollar-for-dollar matching basis and is administered by Caltech. An objective of the Fund is to encourage the interest and participation of university faculty and students in JPL research activities, affording JPL staff members the opportunity for close association with academic researchers. In 1993, the Fund provided resources for 14 new collaborative tasks.

Education and Outreach Programs

During the past year, the Laboratory expanded its varied education and outreach programs in the areas of educational affairs, minority initiatives, community programs and public access.

EDUCATIONAL AFFAIRS

In 1993, JPL established an Educational Affairs Office to oversee activities in university affairs, minority initiatives and educational outreach.

In February, the Laboratory hosted the first regional competition of the National Science Bowl, a coordinated effort to encourage outstanding high school science students. The Science Bowl involves several national laboratories and is part of an education effort sponsored by the Department of Energy.

JPL was one of only two NASA centers to receive a grant from the Department of Energy to implement the Teacher Enhancement Program. The Laboratory supported 36 teachers through this training and support program for middle school teachers from schools with high proportions of minority students.

MINORITY INITIATIVES

JPL's Minority Science and Engineering Initiatives Office sponsored diverse activities in 1993, overseeing over \$2 million in support to historically Black colleges and universities, other minority institutions, the Pasadena (California) Unified School District and the Laboratory's own employees from underrepresented minority groups.

Virgil Shields, the first Ph.D. graduate of JPL's Minority Fellowship Program, developed and demonstrated a new process to consistently produce high-quality monocrystalline beta-silicon carbide at very high bulk growth rates. Shields' work represents an important advance in the attempt to develop new materials that will enable semiconductors and electro-optic circuitry to work faster and more efficiently in the extreme temperature and radiation environments of space. The JPL Minority Fellowship Program is sponsored by the NASA Office of Space Science.

Gloria Brown-Simmons, a JPL employee, led a NASA-JPL endeavor to create a Scientific Visualization Center

at Central State University, a historically Black university in Wilberforce, Ohio. The Center is dedicated to improving both the technological application of visualization and the matriculation of students skilled in this discipline. Brown-Simmons was on loan to the university as part of a program sponsored by the NASA Office of Equal Opportunity Programs.

COMMUNITY PROGRAMS

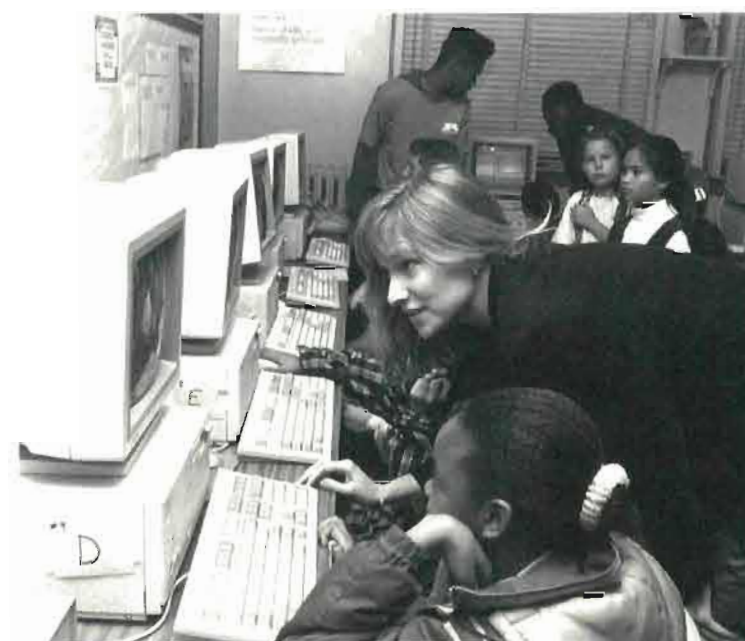
During the year, JPL facilitated several programs to train, educate or otherwise provide opportunities for residents of its neighboring communities. In the JPL-Urban League computer training program, JPL employees voluntarily conducted computer training courses for underemployed and unemployed adults in an effort to improve their job prospects. Participants completing the training were subsequently supported with follow-up work and job placement assistance. The program was

jointly sponsored by the Urban League's Pasadena/Foothill Branch and JPL's Community Action Program Committee.

PUBLIC ACCESS

In January, the Laboratory's Public Information Office opened a public-access computer site that provides computer users around the world with online access to text and image files on JPL activities. The site is accessible directly over the worldwide Internet system and via modems over commercial telephone lines. By year end, the site was averaging more than 7,500 "logons" each month — from most of the United States and from about 50 other countries.

Approximately 9,000 people attended the Laboratory's Open House in June, when nearly 400 employees staffed a range of displays, exhibits, presentations and tours. Guests of all ages enjoyed the opportunity to take a firsthand look at JPL's varied missions and projects.



Laboratory employees assist students in computer science as part of the Pasadena Unified School District's Saturday Science Academy.

Technology Commercialization

A growing technology commercialization effort at JPL seeks to establish working relationships between the Laboratory and private U.S. firms that will improve the nation's posture in the global economy. In 1993, this effort was effectively focused through several programs: technology utilization, software distribution, technology affiliates, small business innovation research, patent licensing and technology cooperation.

TECHNOLOGY UTILIZATION

The *NASA Tech Briefs* publication is a primary vehicle for disseminating information to the general public concerning technology available for commercialization. In fiscal year 1993, JPL produced 28.4 percent — 219 of 771 — of all the *Tech Briefs* published at NASA centers. These *Tech Briefs* resulted in awards totaling approximately \$75,000 to JPL innovators.

Readers of the *Tech Briefs* and other sources regularly make numerous requests to JPL for Technical Support Packages regarding developing technologies. In fiscal year 1993, JPL distributed 47,330 Technical Support Packages, representing 35 percent of the total from NASA centers.

SOFTWARE DISTRIBUTION

Fifteen computer programs developed at JPL during fiscal year 1993 were included in the Computer Software Management and Information Center (COSMIC), the NASA computer repository located at the University of Georgia in Athens, Georgia. Another 11 programs developed at the Laboratory were sent out for beta testing by potential users; one other program was forwarded for use in a scientific collaboration.

TECHNOLOGY AFFILIATES

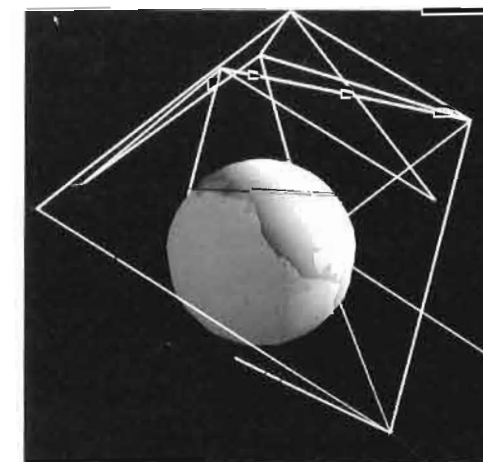
The JPL Technology Affiliates Program gives U.S. companies direct access to the Laboratory's technology base. One-on-one relationships between company employees and JPL personnel facilitate the rapid transfer of solutions to problems that may be costing firms product-introduction time and money. During 1993, the program grew from 32 to 48 participating companies. JPL has performed nearly 160 individual tasks in the five years since the program's inception.

NASA was part of a joint Government agency effort headed by the Advanced Re-

search Projects Agency in the U.S. Technology Reinvestment Project. The project seeks to stimulate a defense industry transition to an integrated, national industrial capability that can provide advanced and affordable military systems and competitive commercial products. JPL participated in the project with 43 other companies or teams of companies to develop programs that will address various national needs.

SMALL BUSINESS INNOVATION RESEARCH

Over the last 10 years, JPL has successfully implemented the Small Business Innovation Research Program to promote small business participation in Federal research and development projects across the nation. Through 1993, as part of this program, JPL had on contract 79 efforts to support small businesses; in addition, the Laboratory evaluated 365 proposals.



PATENT LICENSING

Fifteen patents on JPL-developed technology were licensed during the past year, and an earlier license was renegotiated to mutual advantage. Technologies licensed in 1993 included work on advanced batteries, magnetohydrodynamics, fuel cells, fiber-optics and Hypercube computers.

TECHNOLOGY COOPERATION

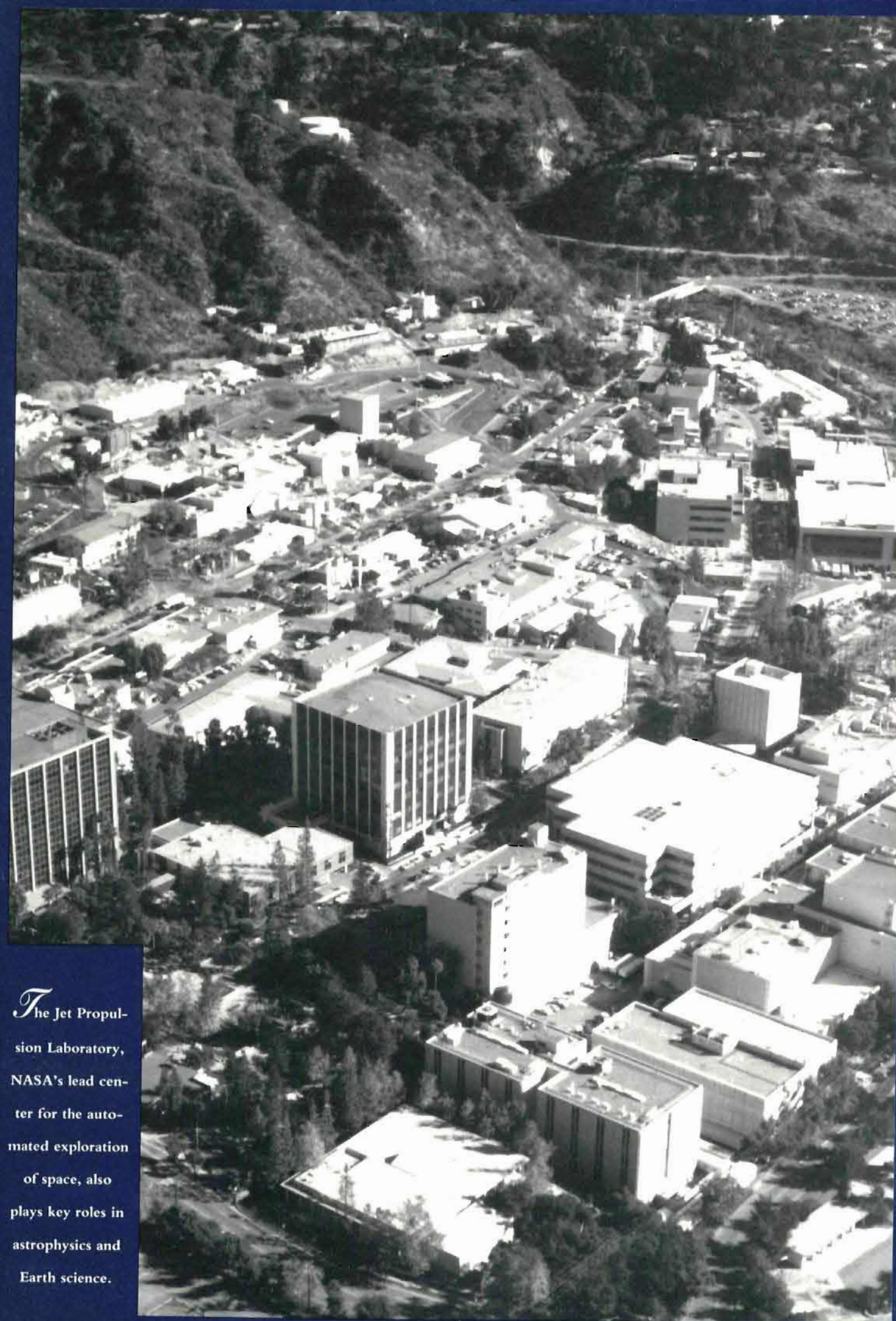
In response to Federal and NASA initiatives, JPL has instituted a program of Technology Cooperation Agreements, with the purpose of pursuing dual use of Federally funded technology through cooperative technology development with U.S. industry. These agreements between JPL and other organizations are mutually beneficial and involve no transfer of funds. In fiscal year 1993, JPL initiated seven such agreements. Eleven others are in various stages of negotiation.

Technology used

in Hypercubes —

concurrent computers developed by Caltech Campus and JPL — was

licensed in 1993. This Hypercube-generated simulation shows multiple satellite communication links.



The Jet Propulsion Laboratory, NASA's lead center for the automated exploration of space, also plays key roles in astrophysics and Earth science.

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